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What If California's Drought Continues?

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Summary

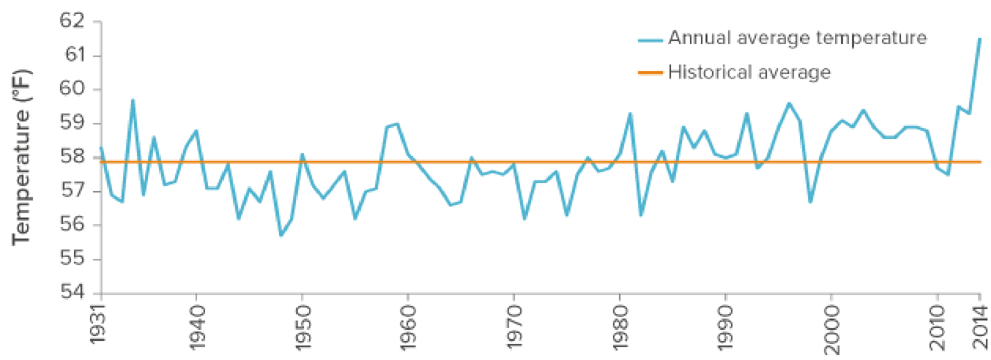
California is in the fourth year of a severe, hot drought—the kind that is increasingly likely as the climate warms. Although no sector has been untouched, impacts so far have varied greatly, reflecting different levels of drought preparedness. Urban areas are in the best shape, thanks to sustained investments in diversified water portfolios and conservation. Farmers are more vulnerable, but they are also adapting. The greatest vulnerabilities are in some low-income rural communities where wells are running dry and in California's wetlands, rivers, and forests, where the state's iconic biodiversity is under extreme threat. Two to three more years of drought will increase challenges in all areas and require continued—and likely increasingly difficult—adaptations. Emergency programs will need to be significantly expanded to get drinking water to rural residents and to prevent major losses of waterbirds and extinctions of numerous native fish species, including most salmon runs. California also needs to start a longer-term effort to build drought resilience in the most vulnerable areas.

Introduction

In 2015, California entered the fourth year of a severe drought. Although droughts are a regular feature of the state's climate, the current drought is unique in modern history. Taken together, the past four years have been the driest since record keeping began in the late 1800s.[1] This drought has also been exceptionally warm (Figure 1). Heat amplifies the effects of drought. It reduces snowpack, a major component of natural seasonal water storage. It decreases soil moisture, stressing natural vegetation and increasing irrigation demands. And it raises water temperatures, stressing fish and other species that live in rivers and lakes.

The combination of low flows and high temperatures make this a "drought of the future"—the type of drought California is increasingly likely to experience as the region's climate warms.[2]

Figure 1. California is experiencing record heat



SOURCE: National Oceanic and Atmospheric Administration.

NOTES: The figure shows annual average temperatures and the historical average for the period 1931 to 2014. For a breakdown by summer and winter months, see technical appendix, Figure A2.

Californians have been working hard to limit the drought's impacts on the state's economy, society, and environment. Since Governor Brown's January 2014 declaration of a statewide drought emergency, an Interagency Drought Task Force has met weekly to coordinate drought management.[3] The state and federal governments have funded emergency drought relief and water system investments intended to boost drought resiliency (Table 1). Local water agencies are collaborating to lessen regional water shortages. And farmers, nonfarm businesses, and residents across the state are stretching available supplies.

Table 1. Drought funding from state and federal sources (millions of dollars)

	State	Federal
Emergency community assistance	$200	$358
Impacted communities, workers (food, housing, training)	$102	$78
Safe drinking water systems	$90	$17
Technical guidance and planning	$8	$14
Feed subsidies for livestock producers*	$0	$250
Emergency ecosystem support	$66	$67
Emergency fire protection	$131	$4
Water system investments**	$2,609	$104
Total	**$3,006**	**$534**

SOURCES: Legislative Analyst's Office and White House fact sheets.

NOTES: The table includes funding from fiscal years 2013–14, 2014–15, and 2015–16. For details, see technical appendix tables A2 and A3.

*In 2015, more than $1 billion was announced to support livestock producers in all western states. We assume California's share will be equal to its 2014 allocation ($125 million).

**Most state water system investment support comes from voter-approved state bond funds. Many of these investments will take some time to implement.

These efforts have helped limit the economic impacts of the drought so far. But the experience is also revealing major gaps in California's preparedness to cope with the social and environmental impacts of extended, warm droughts. Too many decisions are being made on an emergency basis with the hope that the next winter will bring much-needed rain.

It would not be prudent to count on El Niño to end the drought.[4] To stand ready, the state needs to understand what impacts this drought has already had, what impacts to expect if it continues, and what steps may be warranted to prepare for this possibility.

This report provides insights into these questions. We focus on three areas of California's economy and society—cities, farms, and rural communities—and three acute ecosystem management challenges: waterbirds, fish, and forests. The analysis is informed by wide-ranging data sources and by conversations with officials, businesses, and stakeholders on the frontlines of drought management.[5] Table 2 summarizes the likely impacts and management challenges of continued drought, as described here. A technical appendix provides further details.

Table 2. Likely impacts and management challenges if the drought continues

Water availability	
Runoff and storage	Reduced runoff (between 25–40% of average) due to low rainfall and snowpack. Fall reservoir storage at 50% of historic average. Impacts vary regionally depending on precipitation patterns.
Deliveries and curtailments	Supply reduced for farms (8.5–9.0 million acre-feet/year) and cities (2.0–2.5 million acre-feet/year) compared to normal years. Central Valley Project and State Water Project allocations remain at 2015 levels. Surface water shortages require extensive curtailment of water rights, including many senior pre-1914 and riparian rights. Hydropower generation remains at half of recent average, increasing energy costs ($500 million/year or ~2%).
Groundwater	Central Valley continues heavy reliance on groundwater. Excess pumping of 6 million acre-feet/year (with $650+ million additional energy cost for pumping). Increase in dry wells; acceleration of widespread land subsidence and damage to infrastructure.
Water quality	Low flows and high air temperatures cause widespread decline in water quality in rivers and streams. Low reservoirs make managing Delta salinity increasingly difficult.
Cities and suburbs	
Large metropolitan areas have reasonably secure supplies, but require continued conservation efforts and some new supply investments. Isolated communities with a single water source face shortages and require alternative supplies. Some water- and snow-sensitive industries that rely heavily on water (e.g., boating, skiing) face financial hardships, but not enough to dampen statewide economic growth.	
Farms	
Net water shortfall of 2.5–3.0 million acre-feet/year results in roughly 550,000 acres fallowed annually; economy-wide economic losses of more than $2.8 billion, loss of more than 10,000 full-time, part-time, and seasonal farm jobs, and more than 21,000 jobs economy-wide.	
Rural communities	
Increasing number of rural water districts and homes that rely on shallow wells need emergency assistance as wells go dry. Fallowing of farmland exacerbates poor air quality in some parts of the Central Valley and increases economic hardship in farmworker communities.	
Ecosystems	
Native fishes	Record-low flows and high temperatures continue to degrade habitat for native fishes. As many as 18 native fishes face likelihood of near-term extinction, including delta smelt, most salmon runs, and several species of trout. Economic losses for commercial and recreational fisheries.
Waterbirds	Dramatic declines in fall and winter habitat for waterbirds of the Pacific Flyway from reduced water for wetlands and flooded farmland. Bird populations reduced by limited food supplies and disease from overcrowding.
Forests	Extreme wildfire hazard due to high temperatures, dry conditions, and increased tree mortality in California's forests. Severe wildfires (comparable to the 2013 Rim Fire) occur, impacting local communities, watersheds, wildlife, infrastructure, and air quality. Risks of permanent loss of conifer forest ecosystems in burned areas.

SOURCE: See technical appendix Table A10 for details.

NOTES: Assumes two to three more years of 2014 conditions. Reductions in water availability are relative to a normal rainfall year.

Public discussions often frame drought policy in terms of trade-offs among different areas—for instance, cities versus farms, or farms versus fish. And to be sure, the drought is forcing difficult trade-offs. Drought preparedness cannot eliminate all costs and consequences of water scarcity, but it can help lessen vulnerabilities and enable society to handle trade-offs in a transparent and balanced way. Leadership from government, business, and civil society is needed to set priorities and navigate the trade-offs.

Water Availability in a Hot, Dry Time

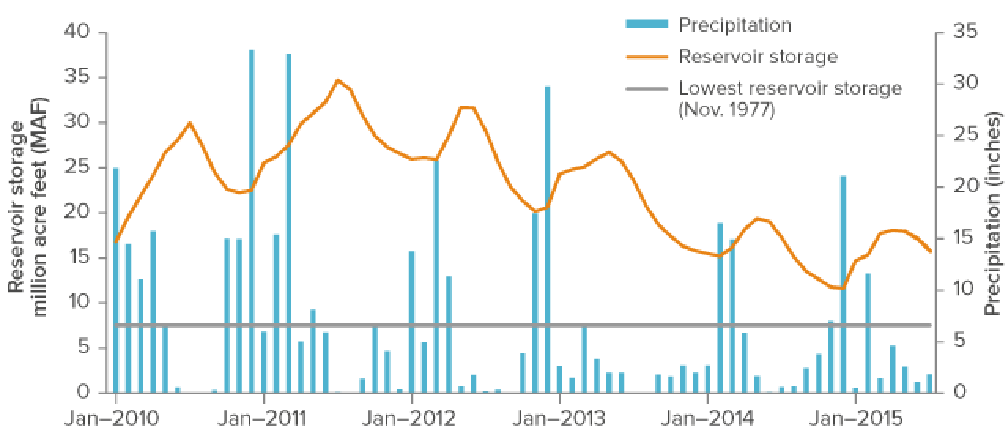
During droughts, California relies on water stored in surface reservoirs and especially groundwater basins to help offset shortfalls in precipitation. This drought is stressing both types of reserves and affecting the amount and quality of water for farms, cities, hydropower, and the environment.

IMPACTS AND ADAPTATIONS SO FAR

Surface Water

Thanks to an unusually wet 2011, the drought began with most surface reservoirs quite full. But these reserves are now significantly depleted (Figure 2). Since 2014, two of the state's largest water providers—the Central Valley Project (CVP) and the State Water Project (SWP)—have dramatically reduced water deliveries to agricultural and urban customers.[6] Deliveries from many local projects have also decreased.[7] Hydropower generation, which relies on releases from reservoirs, is at its lowest level since 1977 (technical appendix Figure A6).

Figure 2. Water stored in surface reservoirs is low



SOURCE: California Department of Water Resources.

NOTE: Precipitation is measured as the sum of the Northern Sierra 8-station and San Joaquin 5-station precipitation indices to account for most rainfall available for reservoir storage. Reservoir storage is the sum of monthly storage in 154 major reservoirs within the state (excluding storage in the Colorado River Basin).

Reduced flows and high temperatures have also affected both the quantity and quality of environmental flows. Water releases from large Sacramento Valley reservoirs help keep salty ocean water from intruding into the Sacramento–San Joaquin Delta, thereby maintaining water quality for agricultural and urban exports and supporting habitat for estuarine fishes such as delta and longfin smelt. These reservoirs are also the primary source of cold water needed by salmon and steelhead that spawn just downstream of the dams. Other water releases—including treated discharges from wastewater facilities—are also important for maintaining environmental flows. Since early 2014, water agencies across the state were granted emergency permits to change the volume, timing, or quality of required outflows 35 times (technical appendix Table A1). As described below, insufficient environmental flow releases at above-normal temperatures have put some fish species on the brink of extinction.

The drought has also exposed weaknesses in the state's technical capacity to forecast the effects of management decisions under extreme conditions of high temperatures and low flows. This has complicated the management of cold water in reservoirs, among other things.

And the drought is revealing strains in the state's surface water allocation system. In California's "first-in-time, first-in-right" system of surface water rights, those with more recent—or junior—rights generally have lower priority in times of shortage. In 2014, the State Water Resources Control Board, which administers water rights and quality standards, ordered curtailment of water diversions by many junior water-rights holders for the first time since 1977; these orders were extended to more senior rights holders in 2015, and the board has also begun issuing fines for non-compliance. Some senior rights holders are challenging the board's legal authority to curtail their diversions.[8] The process has revealed significant gaps in information needed to administer surface water rights in a timely and transparent manner.[9]

Groundwater

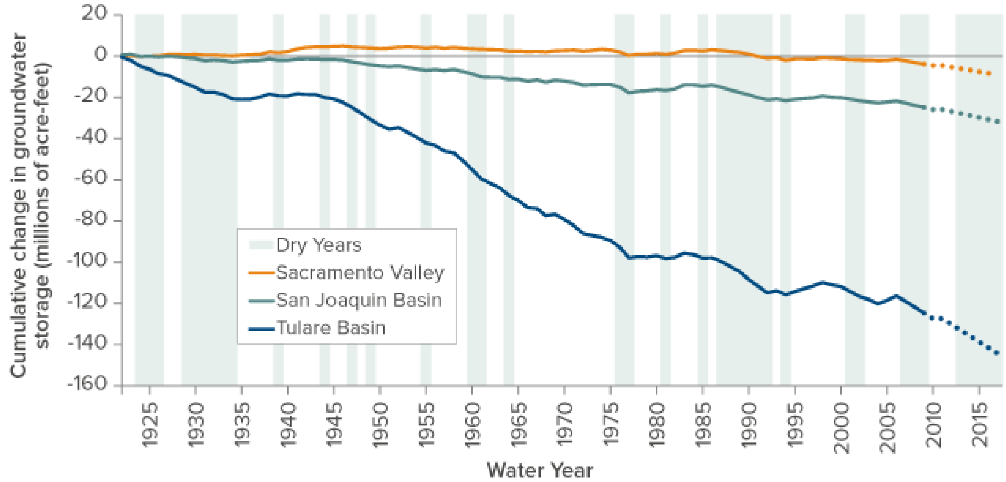
California's groundwater basins have considerably more dry-year storage capacity than its surface reservoirs, and many farms and cities are pumping additional groundwater to meet demands.[10] In a typical year, groundwater supplies about a third of total farm and urban water use. Since 2014, this share has exceeded 50 percent.[11]

Until recently, groundwater has been only loosely regulated by the state. Many urban areas now have well-developed groundwater programs that regulate and charge for pumping to keep groundwater basins from experiencing long-term declines. In contrast, groundwater oversight in most agricultural areas is still limited, and many basins have experienced overdraft—excess pumping that reduces long-term reserves and lowers the water table. Consequences include sinking lands, higher pumping costs, drying up of wells, and drying of some rivers and wetlands fed by groundwater.

Extra pumping during this drought has exacerbated these symptoms of chronic overdraft. Land levels in parts of the southern Central Valley have been falling by more than half a foot annually, causing damage to various types of infrastructure, including bridges, reservoirs, and major water arteries like the Delta Mendota Canal.[12] Falling water tables are raising pumping costs and drying up drinking water wells in some rural communities. In many places, the additional groundwater now being pumped is of poor quality, which lowers crop yields. Conditions are particularly acute in the Tulare Basin—the major agricultural region that includes Fresno, King, Tulare, and Kern Counties—where groundwater supplies have been declining for decades (Figure 3).

Widespread concern over the trajectory of many rural groundwater basins led to the enactment of the Sustainable Groundwater Management Act (SGMA) in September 2014. The act requires water users in the most stressed basins to develop sustainable groundwater management plans by 2020 and reach sustainability by 2040.[13]

Figure 3. Groundwater depletion is a growing challenge in the southern Central Valley



SOURCE: Historical data through 2009 from the California Department of Water Resources; author estimates after 2009.

NOTE: For changes after 2009, we assumed continued depletion of groundwater storage at the same rate as 2008–09, the third year of the last drought. The exception was 2011, a very wet year, for which we assumed that levels remained stable. Since surface water availability has been tighter during this drought, this method may underestimate recent depletions.

WHAT IF THE DROUGHT CONTINUES?

To consider the impacts of continued drought, we assume that the dry, hot conditions of the past two years will persist for at least another two to three years. One caveat is that worse conditions—and worse impacts—are possible. For instance, 1977 was drier than the driest years of the current drought (technical appendix Figure A1). Another caveat is that droughts often have considerable geographic variability. For example, 2015 saw record-low snowpack in the Sierra Nevada and near-record-low runoff in the Central Valley. Yet conditions in some North Coast communities improved dramatically thanks to isolated, intense winter and spring rains.

Continued drought will put additional stress on both surface and groundwater resources (technical appendix Table A10). Because the state's major Central Valley reservoirs have already drawn down most of the reserve built up by the 2011 rains, surface water deliveries from the CVP, SWP, and local projects will have to primarily rely on annual precipitation, as they did this past year. This means water deliveries will stay at least as low as currently—and possibly even fall lower—depending on decisions made regarding reservoir management for fish and wetlands and salinity in the Delta. Low flows and high temperatures will exacerbate declines in water quality in rivers and streams.

Groundwater will remain the primary drought reserve. But in some parts of the agricultural heartland, this will come at increasing costs, including more energy for pumping, more dry wells, reduced crop yields as water quality falls, and more damage to infrastructure from sinking lands.

Four Key Areas of Concern

The drought has left no part of California untouched, and continued drought will pose added—and in some cases acute—challenges. The severity of threats varies across management areas, reflecting both underlying vulnerabilities to water scarcity and the degree to which managers have prepared for and adapted to drought. Cities and their suburbs, where most Californians live and work, have been adapting fairly well. Farms—the economy's largest water user—have also been adapting, but they are inherently more vulnerable. Rural communities are home to the most vulnerable Californians, facing both job losses and drinking water shortages. California's ecosystems are in crisis. Fish and waterbirds that rely on freshwater in rivers, estuaries, and wetlands are under extreme stress, and extinctions are likely. And trees in California's forests are dying at record rates, raising risks of devastating wildfires.

CITIES AND SUBURBS

If this drought has one bright spot, it is that California's cities and suburbs—home to 95 percent of California's population and an even higher share of economic activity—have become considerably more resilient since the 1987–92 drought, despite the addition of more than eight million residents since that time.[14]

Impacts and Adaptations So Far

Whatever impacts the drought may be having on the California economy, they have not been significant enough to derail a strong economic expansion fueled by other economic advantages in the state. Since 2011, California's real GDP and nonfarm employment have been growing at a faster pace than the national economy as a whole.

In part, the economy's drought resilience reflects the small share of farming in the state's economy (1–2%), and the fact that California now has relatively few nonfarm industries that are particularly water sensitive. But it also reflects the preparation urban water utilities have made to withstand droughts.

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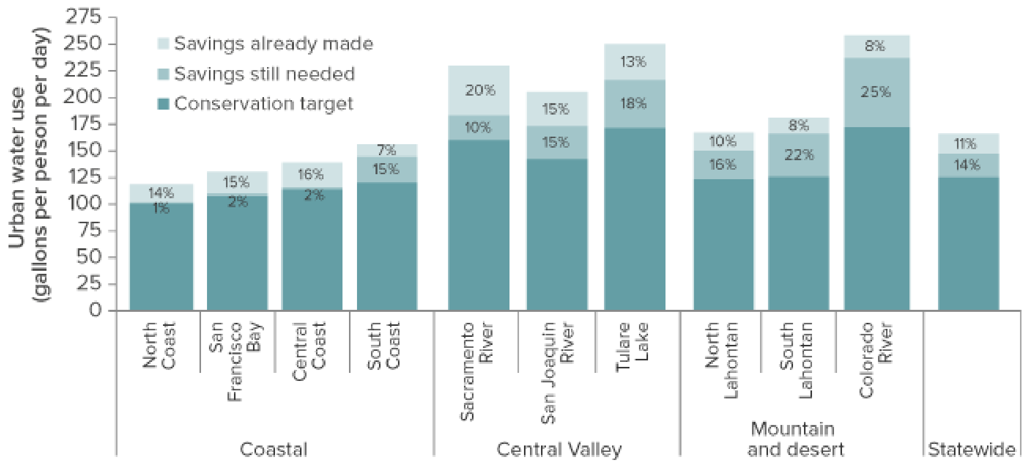
Since the early 1990s, water utilities have invested heavily in indoor conservation, surface and underground storage, new interconnections that enable supply sharing with neighboring agencies, use of recycled wastewater and stormwater, and water purchases through the state's water market.[15] This more-diversified portfolio enabled cities to enter this drought in good shape.

Improved regional cooperation is also helping cities cope. Water utilities are regularly sharing information and infrastructure and—where needed—supplies. As an example, Sacramento area agencies are collaborating to improve access to shared groundwater reserves as a back-up source for communities reliant on Folsom Reservoir, where water levels are low and falling.

Increased conservation is also a staple of the urban drought management toolkit. In May 2015, the State Water Board introduced a statewide urban conservation mandate, requiring 25 percent average savings compared to 2013. The mandate went further than many utilities would have gone on their own this year, given their local supply conditions. Statewide, utilities were nearly half way there (11%) by the time the mandate went into effect (Figure 4). In high-water-use regions the board set higher standards for water conservation. Attaining the target will require large reductions in outdoor water use, which often exceeds half of the urban total.[16] Although this will entail some initial costs and inconvenience, it need not diminish quality of life in California communities. The popularity of turf buyback programs—which give rebates to replace thirsty lawns with plants that use less water—suggests that Californians may be ready to permanently reduce urban outdoor water demand.[17]

Figure 4. Some communities are still well above state water conservation targets



SOURCE: Author estimates, using monthly urban water supply data from the State Water Resources Control Board. (See technical appendix Table A4 for details.)

NOTE: The figure shows per capita urban water use, including residential and commercial, institutional, and industrial customers. The "conservation target" is the targeted water use under the new state mandate, which went into effect in June 2015. "Savings already made" is the difference between water use in 2013 and the 12 months ending in May 2015. The North Lahontan region covers most of the northeastern Sierra; South Lahontan covers the eastern Sierra and high desert including Mono, Inyo, and parts of Kern, Los Angeles, and San Bernardino Counties; and the Colorado River region covers the southeastern portion of the state including Imperial and parts of Riverside, San Bernardino, and San Diego Counties.

If the Drought Continues

Can California's cities remain resilient? This question really has two parts: First, are water solutions available to avoid extreme scarcity? And second, will water management remain flexible enough to avoid large economic and social consequences?

Based on our conversations with water managers in major regions of the state,[18] the answer to the first question generally seems to be "yes." Many water utilities still have significant supplies in storage,[19] and their conservation programs are reducing near-term demands. Efforts are now underway to accelerate new investments in recycled wastewater, stormwater capture, groundwater clean-up, improved conveyance, and other measures.

Drought fixes to existing infrastructure are also in the mix. Examples include installing a lower water intake on Folsom Reservoir and pumping water upstream on the California Aqueduct and the Delta Mendota Canal to deliver water to locations north of Kern County groundwater banks and San Luis Reservoir.[20]

Lost hydropower production will have economic costs—on the order of $500 million in 2015—but recent increases in renewable energy sources have helped make up for shortfalls. And new efforts are reducing other water-related vulnerabilities of California's power grid—for instance, by making sure thermal power plants have adequate and diverse supplies for cooling, including recycled wastewater.[21]

For water utility managers, key issues appear to be cost (in particular, avoiding the most expensive solutions until necessary) and the pace of regulatory approvals for new projects. Recent legislation providing exemptions to the California Environmental Quality Act (CEQA) for recycled water project standards will help in this regard.[22] The state's emergency drought funding program (Table 1) has also aimed to speed up the disbursement of state bond funds to support new water projects.

Implementation of the conservation mandate sheds light on the second question: Will drought water management be flexible enough to avoid large costs? The mandate was adopted as an emergency measure, and its water savings will make it easier for many communities to weather a longer drought. But it also raises some economic and social challenges. Because utilities lose money when water sales fall quickly, the mandate creates a fiscal crunch: net revenues are expected to fall by $500 to $600 million in 2015.[23] This will tap financial reserves when new investments to boost supplies may be needed. Sooner or later, utilities will need to adjust rates to make up the shortfall. Since a recent court ruling regarding Proposition 218 (a constitutional amendment that affects water pricing), utilities face new legal constraints in setting higher rates for higher levels of use.[24] And if they recoup their losses by raising fixed service fees rather than per-gallon charges, there are equity concerns because fixed fees hit lower-income households hardest.[25]

There can also be broader economic consequences if utilities indiscriminately apply conservation mandates to businesses. California is fortunate not to have many nonfarm businesses that require large volumes of water, and many businesses still have considerable room to conserve. But businesses that use water in their production processes—such as food and beverage processing—often have less flexibility than households to reduce water use without affecting competitiveness.[26] The new state mandate does not account for the fact that some communities have a much higher share of commercial and industrial water use than others.[27] Although larger utilities generally appear to be avoiding cutbacks that would cost jobs, utilities in some middle-sized, high-water-use communities have imposed across-the-board cuts on residents and businesses alike.

If the drought continues, both the state and water utilities should maintain some flexibility in applying conservation targets. Additional regulatory streamlining for urban supply projects may be warranted, as well as reform of the legal framework for rate setting. Urban areas—like farmers—would also benefit from improvements in the state's water market, which is not sufficiently transparent or flexible as a drought-management tool.[28] Over the longer term, the state should be encouraging utilities to continue to bolster supply investments as well as conservation efforts. Rigid conservation mandates can discourage such investments, because they can prevent communities from taking full advantage of the increased supplies.

FARMS

California's productive farm sector requires large volumes of water for irrigation, typically four times the annual use of cities.[29] This strong water dependency—along with the sector's sheer size—makes farming inherently vulnerable to droughts. Adaptation options are also more limited than for cities, which can generally afford higher-cost water supplies.

Impacts and Adaptations So Far

Like cities, California farmers have been adapting to water scarcity over the past few decades. They have made major investments in irrigation efficiency and shifted toward crops that generate higher revenues per unit of water used.[30] Some places (notably Kern County) have also invested in storing water in groundwater basins for use by local farmers and partner agencies in urban areas.[31]

Yet with the exception of new groundwater storage, these adaptations have generally not boosted drought resilience. In most places, irrigation efficiency has improved crop yields and quality, but not overall water availability.[32] That is because irrigation water in less efficient systems generally is not wasted; water not consumed by crops either returns to streams, where it is reused by others, or else percolates through soils to recharge aquifers.[33] Meanwhile, the long-term shift to high-revenue perennial nuts, fruits, and vines has made agricultural water demands more rigid, because these orchards must be watered every year to maintain farmers' investments.

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As a result, farmers have been hit hard by reduced surface water deliveries.[34] In 2014, Central Valley farms lost roughly a third of normal surface water supplies, or 6.5 million acre-feet (maf). In 2015, the deficit may rise to 8.7 maf. Economic losses from this cutback have been relatively modest so far because farmers in many places—including the southern Central Valley—have been able to pump additional groundwater: an extra 5 maf statewide in 2014 and as much as 6 maf in 2015.

Water trading has also helped keep the most profitable crops in production.[35] Strong commodity prices have also bolstered the farm economy during the drought, even encouraging new plantings of permanent crops such as almonds.

Statewide, farmers fallowed approximately 5 percent of cropland in 2014—mostly more flexible and lower-revenue field crops like rice—and that share is likely to increase slightly this year. The costs of fallowing and extra groundwater pumping—including the spillover effects on the rest of the economy—were on the order of $2.2 billion in 2014 and $2.7 billion in 2015. Direct costs for farmers were 3–4 percent of the roughly $47 billion in annual farm revenues.

Fallowing land also has both on- and off-farm effects on employment. Total farm employment has actually been increasing slightly despite the drought because the higher-revenue crops farmers are focusing on generally employ more people than the lower-revenue field crops that farmers are scaling back.[36] But with normal water supplies, California would have had an additional 7,500 full-, part-time, or seasonal farm jobs in 2014 and an additional 10,100 farm jobs this year. Taking into account spillover effects on the rest of the economy, there would have been an additional 17,000 jobs economy-wide in 2014 and 21,000 this year.

If the Drought Continues

A sharp fall in revenues or jobs statewide is unlikely. Instead, California should expect progressive increases in economic losses, particularly in the Central Valley, as yields on perennial crops decline from reduced watering and use of lower quality groundwater (Table 2 and technical appendix Table A5). Although groundwater pumping is becoming more costly, there are still abundant reserves in many places, and high commodity prices make this extra pumping affordable.

Over the longer term, implementation of the 2014 Sustainable Groundwater Management Act (SGMA) will make California farming more resilient to future droughts. The concept, already used by many urban agencies, is to pump less—and recharge basins more—in wet and normal years. This makes groundwater more readily available (at lower cost) during droughts. And it lessens the threat of external costs in terms of local infrastructure damage from sinking lands and drying of shallower wells. Management actions under SGMA do not have to start until 2020, but banks are already changing their long-term farm lending practices with SGMA in mind—a sign that the market may help quicken the pace of implementation.[37]

Over the longer term, implementation of the 2014 Sustainable Groundwater Management Act (SGMA) will make California farming more resilient to future droughts.

In the near term, extra groundwater pumping is an important drought mitigation tool to reduce agricultural losses. But there is no system in place to mitigate the external costs of pumping. If the economic benefits from pumping outweigh these costs—as they well may—it could make sense to charge a mitigation fee to cover them rather than limit pumping during droughts.[38] If this proves too difficult, counties may wish to enact emergency ordinances that restrict new or deeper wells in areas of special concern.[39]

As with cities, farming would also benefit from improvements in the water market. Although trading has already helped somewhat, a more transparent, streamlined approval process could help move scarce water to the most economically productive farming areas, boosting both revenues and jobs.

RURAL COMMUNITIES

The drought is increasing hardship for California's small rural communities, which are already some of the state's most disadvantaged.

Impacts and Adaptations So Far

Farmland fallowing has cut jobs in some rural communities, and others have been hurt by declines in water-based recreational activities such as fishing and boating.[40] Drinking water supplies—already a problem in some areas because of contaminants such as nitrate—have been further compromised by the drought.[41] Many rural households rely on shallow domestic wells or small, poorly funded community water supply systems. As of early July 2015, more than 2,000 dry domestic wells were reported, mostly in the Central Valley and Sierra, with more than half in Tulare County (technical appendix Table A7). Emergency water supply needs have also been identified for more than 100 small water community water systems around the state (technical appendix Table A6). Particulate air pollution from a combination of heat, dust, and fires has also increased in the San Joaquin Valley, likely exacerbating asthma and other health problems.[42]

State and federal governments recognized the vulnerability of rural communities early on and made emergency funding available for food and other support for impacted workers and for safe drinking water (Table 1).

Over the past two years, the state has significantly improved its emergency response for communities lacking drinking water. The multiple agencies involved have strengthened coordination to identify needs and deliver help.[43] Some community systems have gotten new wells and pipelines. In a few cases, people with dry domestic wells have been hooked up to local water systems. But in most cases, the solutions are stopgap: trucking in bottled water or delivering water to temporary holding tanks.[44] And in many places, the process for getting water to households in need is still too slow and difficult.

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Only some counties (including Tulare) have a system for collecting information on dry wells, so it is likely that the scale of the problem is much larger than suggested by state data. State and federal funding rules are cumbersome, making it difficult to move quickly even on stopgap solutions. And the wait times to schedule well drillers to deepen or replace dry wells is very long—now typically 18 months.

If the Drought Continues

Community and domestic wells will run dry at an increasing pace, and emergency support programs will need to expand and improve. One priority is to make it easier for individuals to seek help if their wells run dry. Another is to strengthen the tracking system for addressing problems once they are identified. Longer-term solutions will also be needed to durably address both water supply and quality in these communities because many dry wells are unlikely to return to normal even after the rains return. The state has recently improved its institutional capacity to provide longer term assistance, and some new bond funds are available, but a long-term funding source is still needed to tackle this problem.[45]

ECOSYSTEMS

The most acute and severe impacts of this drought so far are on California's freshwater habitats and forested lands and on the biodiversity they support. These impacts stem, in part, from the severity of the drought and its combination of low flows and heat. More than a century of water and land practices have increased vulnerability by undermining the natural capacity of these ecosystems to handle occasional droughts.[46]

The environment doesn't have the same kinds of adaptation tools as other sectors—it generally can't pump more groundwater in dry times, for example.[47] But this troubling situation also reflects less investment in building drought resilience for the environment. California was unprepared for this environmental drought emergency and is now struggling to implement stopgap measures.

Here, we focus on three major management challenges of continued drought: risks to waterbirds of the Pacific Flyway from loss of wetlands, risks to native fishes from conditions in rivers and streams, and the growing potential for extreme wildfires.[48] Near-term water and land management changes can help address the urgent problems for waterbirds and fish, but this will require additional emergency funding.

WATERBIRDS

California is home to diverse populations of ducks, geese, shorebirds, and herons and is an essential stopping point on the Pacific Flyway. Wetlands in northeastern California and the Central Valley provide winter habitat for more than five million waterbirds.[49] Twentieth century land development drained most natural wetlands, so these birds now rely on a network of managed wetlands—intentionally flooded areas in federal and state refuges and on private lands.[50] They also make extensive use of flooded farmland, most notably rice farms that are flooded in the fall and winter to break down rice straw.[51]

Impacts and Adaptations So Far

The drought has dramatically reduced the amount of waterbird habitat. Water deliveries to refuges —already tight in normal times—were cut by 25 percent or more, and the sharp drop in rice acreage reduced the availability of flooded farmland.[52] In addition to reducing food supplies, reduced wetland habitat increases risk of disease because crowding can decrease water quality.

So far, management actions and lucky timing of late spring rains have helped stave off major declines in bird populations. Close coordination between wildlife refuges across California in the past year has also helped ensure that limited water is distributed to wetlands when it can provide the greatest habitat value for birds.

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Another promising effort is paying farmers to make small adjustments in the timing and duration of flooding fields. For modest amounts of money, these "pop-up habitats" can be strategically located to make the most use of limited water availability. The Nature Conservancy's BirdReturns is one such program, supported to date with philanthropic sources.[53] Federal funds support a similar program run by the Natural Resources Conservation Service.[54] These programs are prime examples of adaptively managing scarce resources to create a high return on investment.

If the Drought Continues

Risks of high bird mortality are increasing as the drought wears on. The Nature Conservancy estimates that refuges may face larger water cutbacks this coming winter, and that temporary wetlands in rice fields may be reduced by more than 85 percent.[55] Absent rains, food for ducks and geese will become critically scarce this coming fall precisely during the peak of bird migration.[56]

A continuation of current management efforts can help reduce ongoing drought impacts, but this will require dedication of both refuge water supplies and funds for purchasing farm water, which may become more costly as the drought wears on.

NATIVE FISHES

California is home to 129 species of freshwater fish, two-thirds of which are found only in the state. One hundred of these fishes are either already listed as threatened or endangered under federal and state Endangered Species Acts or in decline and on their way to being listed in the future.[57] Many are highly vulnerable to low flows and higher water temperatures, and this drought is taking a major toll.

Impacts and Adaptations So Far

Since 2013, rivers and streams throughout the state have been at record or near-record lows, with many waterways that would normally flow year-round becoming a series of disconnected pools or drying up (technical appendix Figure A4). Higher temperatures have increased stress on fishes, most notably salmon and trout, as well as some amphibians. Survey counts for estuarine fish such as delta smelt and longfin smelt are at or near record lows.

Emergency management actions have included drought-stressor monitoring and rescue operations by the Department of Fish and Wildlife (technical appendix Table A8). In several key salmon and steelhead streams, the State Water Board has ordered some water users to stop diversions or to reduce groundwater pumping that was depleting surface flows.[58] But, as noted above, the board has also relaxed environmental flow standards on 35 occasions to accommodate urban and farm users (technical appendix Table A1).

While water managers have sought to manage the timing of flows in ways that benefit both fish and other water users, they have not always had that option. The drought has posed difficult trade-offs in managing scarce surface water, where goals of water supply, water quality, and fish flows often compete. This is best illustrated by ongoing efforts to preserve the 2015 cohort of winter-run Chinook salmon below Shasta Reservoir. Unplanned releases of warm water in 2014 caused a near-complete loss of wild-spawning winter-run eggs and fry.[59] Decisions made this year are likely to lead to a similar result, pushing this species very close or possibly to extinction. Restrictions on releases from Shasta Reservoir to try to correct these mistakes are affecting operations of Oroville and Folsom Reservoirs, reducing agricultural and urban supplies and making it difficult to meet salinity standards for water exports from the Delta.

If the Drought Continues

Eighteen native fish species appear to be at high risk of extinction in the wild, including most runs of salmon and steelhead and a diverse group of other fishes that reside in watersheds across the state.[60] Reasons include loss of rearing or spawning habitat due to reduced flows (an issue for all 18 species) and increased water temperatures (an issue for salmon, steelhead, and several other fish including delta smelt). The drought is also favoring conditions for invasive species that reduce the quality of habitat for some fish. For some salmon runs, an added stressor is the release of large numbers of hatchery-bred fishes, which can harm drought-stressed wild fish through competition, predation, or interbreeding that reduces the fitness of their offspring.

Beyond the fish rescue and monitoring efforts noted above, there is no comprehensive plan to address the potential for extinctions.

The drought has posed difficult trade-offs in managing scarce surface water, where goals of water supply, water quality, and fish flows often compete.

Near-term options for improving habitat in the wild are limited but could help in some cases. For instance, managing some smaller watersheds as refuges by restricting diversions and focusing restoration efforts could help some salmon runs. Better enforcement efforts may also help, especially where illegal diversions to marijuana farms and vineyards are depleting North Coast streams.[61]

And more generally, allowing a greater margin of safety on environmental flows for fish earlier in the season could improve chances of fish survival, though this would reduce availability of water for farms and cities. Creative approaches to acquire water and use it strategically, as in the BirdReturns case, could reduce conflict. Although the Department of Fish and Wildlife has tried to secure additional flows through voluntary agreements, the response has been limited. A sustained effort utilizing emergency funding to purchase water in selected watersheds may be needed to prevent extinctions.[62]

For many of these fish, it will also be prudent to develop a plan for protecting the species in captivity and rebuilding populations following the drought. This would mean expanding the state's program of conservation hatcheries—those specifically run to protect biodiversity. This would require rapid and substantial investments of resources because the state currently lacks the facilities, funding, and technical expertise to systematically pursue such an approach.[63] This approach would also be controversial because it would likely require shifting most current hatcheries away from producing fish for commercial and recreational fisheries, which are already taking a financial hit from fewer fish during this drought.[64]

FORESTS AND WILDFIRES

Conifer and hardwood forests cover roughly a quarter of California. These forests are naturally wildfire prone, and a century of suppressing fires has made them much denser, increasing the likelihood of large, devastating fires.[65]

Impacts and Adaptations So Far

Hotter temperatures, moisture deficits, and insect infestations are killing trees at a rapid pace. These conditions lead to severe wildfires, posing significant threats to public safety, power lines and other infrastructure, water supply, air quality, and wildlife. Since the start of this drought, California has experienced two of the three largest fires in recorded history (technical appendix Figure A9). When fires burn hot over large areas—as in the 2013 Rim Fire in and near Yosemite National Park—there is also a concern that conifer forest ecosystems may not recover.

CALFIRE's strategy for this drought, in partnership with federal and local authorities, is to reduce the potential for large, destructive fires by suppressing fires as quickly as possible.

If the Drought Continues

California faces significant risk of more devastating fires like the Rim Fire over the next two to three years.

Given the scale of wildfire risk, CALFIRE's fire suppression strategy is the only real near-term option. But this strategy could become harder as the drought wears on and forest conditions degrade. Management options to reduce severe fire risk will be of limited value in the short term, given the problem's vast scale. Fuel reduction efforts that can reduce fire intensity—including thinning and reintroduction of more frequent, low-intensity fires—require sustained efforts over large areas for decades. Although some efforts are underway on private lands, fuel reduction efforts on federal land—roughly half the forested lands in California—have proven difficult for a variety of reasons, including permitting.[66]

Building Drought Resilience

The ongoing drought has served as a stress test for California's water management systems, and continuing drought will test them further. Managers and businesses are employing an array of tools and strategies. Many of these have helped California reduce drought impacts. Others will need refinement and further investment.

Current drought actions fall into three general categories: those that are working well and may need minor improvements; those that are still works in progress, requiring support and refinement; and those that require substantial policy reforms or investments.

WHAT'S WORKING

- **Diversified water portfolios:** Historic investments in diversifying water supply sources and managing demand have yielded great benefits. Further investments could be aided by streamlined permitting, as with recent CEQA exemptions for recycled wastewater standards.
- **Regional infrastructure:** Coordinated infrastructure development among multiple agencies has built regional diversity in water supplies and reduced vulnerability.
- **Coordinated emergency response:** Unprecedented coordination among state, federal, and local agencies has improved emergency response and reduced the economic costs of the drought.

WORKS IN PROGRESS

- **Mandatory conservation:** Although highly successful at reducing urban use, statewide conservation mandates can have unintended economic and social consequences if they are not implemented with some flexibility. They can reduce local financial capacity and appetite for new supply investments, and they can cost jobs if they are not considerate of business water use. They can also convey an overly negative impression about urban water conditions in the state—potentially dampening future business investments.
- **Water pricing:** Many urban utilities have encouraged conservation with tiered water pricing, but they now face significant uncertainty about the legality of these rates. Low-income households are vulnerable if utilities make up for lost water revenues with higher fixed monthly fees. Legal reforms to Proposition 218 may be needed to support both efficient and equitable pricing.[67]

- **Rural community supplies:** Some domestic and small community water supplies will always be vulnerable during droughts, and emergency response has improved. But the mechanisms to report dry wells should be strengthened and response times shortened for getting water to affected residents. Continued progress is also needed to provide long-term safe water solutions to rural communities.

- **Groundwater management:** Groundwater is a vital drought reserve, and extra pumping has reduced the economic costs of the drought. The new Sustainable Groundwater Management Act will boost the long-term drought resilience of California's farming sector and reduce negative impacts of unsustainable pumping. State and federal support for key technology and tools—such as groundwater models and well metering—can enable locals to move faster in implementing the law.[68] Addressing acute short-term impacts of pumping, such as infrastructure harm from sinking lands, may require charging new pumping fees or limiting new wells in some areas.

- **Water trading:** Water trading has helped reduce the economic costs of the drought so far, and it will be vital if the drought continues. But the market is not sufficiently transparent or flexible. Processes for approving trades are complex and often opaque. Little information is publicly available about trading rules, volumes, or prices.[69]

- **Waterbird management:** The risks to waterbird populations can be reduced by coordinating the management of water on refuge wetlands and flooded farm fields. State and federal investment in creative approaches, such as programs that pay farmers to flood fields, can yield great benefits with limited water and funds.

DIFFICULT WORK AHEAD

- **Improving the curtailment process:** In principle, California's seniority-based water-rights system is designed to handle droughts. But making it work well will require better information on water availability and use, clearer state authority, and more effective enforcement.

- **Modernizing water information:** To facilitate all facets of water management—including trading, curtailments, and environmental flows—the state will need to make major investments in the collection, analysis, and reporting of water information.[70] This includes updating models to consider the extreme temperature and flow conditions of modern droughts.

- **Managing wildfires:** The stopgap measure of suppressing fires during drought may work in the short-term, but a long-term strategy of improved forestry and fire management—with strong federal participation—is needed.

- **Managing surface water trade-offs:** The state and federal governments have not gone through the difficult exercise of defining and prioritizing objectives among competing uses of scarce supplies, especially when managing reservoirs. The difficulties of managing Shasta Reservoir to protect wild salmon highlight the need to do better forecasting and build in a margin of safety for environmental flows.

- **Avoiding extinctions of native fish:** Continued drought will likely lead to multiple extinctions of native fish species in the wild, and California lacks a plan to address this. More cautious strategies to save reservoir water for environmental flows may help, and purchasing water to boost flows could reduce conflicts. It may also be prudent to make immediate investments in conservation hatcheries.

- **Building environmental resilience:** Beyond stopgap measures, California also needs to invest in improving the capacity of our native biodiversity to weather droughts and a changing climate. This requires a plan and the funding to put it into action.[71]

Conclusion

Since statehood, California has developed water supply infrastructure and supporting laws to manage water scarcity during droughts. Yet the intensity and duration of the ongoing drought is stress-testing the state's management systems. In many respects, this drought is California's dry run for a drier, warmer future.

Californians at all levels have shown a commitment to reducing the economic, social, and environmental harm from the drought with many successes. Yet if the drought continues for another two to three years, the challenges will grow. Addressing the most pressing threats will require stopgap measures—for instance, delivering drinking water supplies to rural residents with dry wells, setting up conservation hatcheries to prevent fish extinctions, and making spot decisions about tough trade-offs. But the state also needs to leverage the lessons of the past four years to build longer-term drought resilience. That way, we will be more prepared for future droughts and have less need for stopgap, emergency solutions.

NOTES

1. See technical appendix Figure A1 and related discussion.
2. J. Mount and D. Cayan. "A Dry Run for a Dry Future" (PPIC blog, May 27, 2015).
3. A list of state drought actions.
4. Some long-range models indicate that a strong El Niño may improve rainfall in California next winter, but the reliability of these forecasts is low and the relationship between El Niño and precipitation in Northern California is weak. See D. Cayan and J. Mount, "Don't Count on El Nino to End the Drought," (PPIC blog, July 9, 2015).
5. We spoke with close to 50 individuals, representing 11 state and federal agencies, urban water agencies in five regions, agricultural water supply, food processing, and lending activities, and nonprofits working on rural water supply and environmental management.
6. CVP settlement and exchange contractors, a group of agricultural districts that usually get 100 percent of their contractual amounts, received 75 percent in 2014, and may receive just 55 percent in 2015. CVP urban customers south of the Delta, including Santa Clara Valley Water District, were cut from the usual 75 percent to 25 percent. Some CVP agricultural contractors have received 0 percent of their contracts since 2014 (down from a 2008–13 average of 64% for those located north of the Delta and 39% for those located south of the Delta). SWP Feather River Settlement Agreement holders, agricultural districts that usually get 100 percent of their contracts, got only 50 percent in 2015. Regular SWP urban and agricultural contractors, who received an average of 50 percent from 2008–13, got just 5 percent in 2014 and 20 percent in 2015.
7. For instance, the Los Angeles Aqueduct, which conveys water to LA from Mono Lake and Inyo County, is projected to deliver just 32,000 acre-feet this year: the lowest since its construction (mostly from pumped groundwater rather than snowmelt runoff). Deliveries since 2008 have averaged 150,000 acre-feet/year.
8. See for instance D. Kasler and R. Sabalow, "Water Rights Ruling a Setback for California Drought," *Sacramento Bee*, July 10, 2015.
9. See for instance F. Nirappil, "California Drought: Regulators Say First Water Diversion Prosecution Aided by Detailed Records," Contra Costa Times, July 23, 2015. For a discussion of information needs, see J. Mount et al., *Policy Priorities for Managing Drought* (PPIC, 2015).
10. California's groundwater basins hold at least three times as much usable water as state surface reservoirs, and a large share of surface reservoir storage is for seasonal uses, not carryover storage for dry years. See J. Lund et al., *California's Water: Storing Water* (PPIC, 2015).
11. For groundwater use from 1998 to 2010, see C. Chappelle et al., *Reforming California's Groundwater Management* (PPIC, 2015). Recent estimates of more than 50 percent are based on work by R. Howitt et al., described in technical appendix Table A5.
12. For a general overview, see California Department of Water Resources, *Summary of Recent, Historical, and Estimated Potential for Future Land Subsidence in California*, 2014. During the drought of the late 2000s, the US Geological Survey found land sinking, or subsidence, rates ranging from 1 to 21 inches over a three-year period. These rates are likely to be accelerating with the pumping now occurring. (M. Sneed et al., *Land Subsidence along the Delta–Mendota Canal in the Northern Part of the San Joaquin Valley, California, 2003–2010*: US Geological Survey Scientific Investigations Report 2013-5142.) For a discussion of impacts to Sack Dam, where continued subsidence will cost local farmers $10 million to move water, see "California farmers dig deeper for water, sipping their neighbors dry," *New York Times*, June 5, 2015. Subsidence-related damage to a bridge over a canal in Fresno County will cost $2.5 million to repair. See "Groundwater pumping causing Central Valley bridges to sink," KSFN, July 21, 2015.
13. Basins identified as critically overdrafted need to meet this timeline. Other priority basins have an additional two years to adopt and start implementing their plans. The law gives local agencies the authority to implement the plans, including the ability to measure use and charge fees for pumping. The State Water Board can intervene if it deems local efforts inadequate.
14. The urban population share is from the 2010 US Census. For a discussion of the economic statistics in this section, including the urban economy's share of economic activity and recent GDP and employment trends, see the technical appendix discussion of nonfarm economic impacts.

15. For instance, the Metropolitan Water District of Southern California has increased storage more than 13-fold since the early 1990s (Metropolitan Water District of Southern California, Regional Progress Report. Implementing the Diversified Resource Portfolio. February 2014, p. 3). See our map of per capita water use trends. For a discussion of water trading trends, see technical appendix Figure A5.
16. E. Hanak et al., *California's Water: Water for Cities* (PPIC, 2015).
17. The largest program is run by the Metropolitan Water District of Southern California. Following the success of a $100 million rebate program, Met's board approved an additional $350 million in rebates—enough to replace roughly 4,000 acres of turf. The program was fully subscribed within the first month. M. Stevens and M. Moran, "Southland Water District Ends Popular Lawn-Removal Rebate Program," *Los Angeles Times*, July 10, 2015.
18. We spoke with officials from urban water agencies about conditions in their regions in the Sacramento area, North Coast, San Francisco Bay Area, Fresno area, and Southern California.
19. For many Central Valley cities, this includes substantial groundwater reserves. San Francisco's Hetch Hetchy reservoir, which serves many Bay Area communities, began this summer at 95 percent capacity. Metropolitan Water District of Southern California's reserves were substantially diminished last year, but they began the summer with nearly 1.2 million acre-feet in dry year storage, including surface reservoirs on the Colorado River system and groundwater basins (Metropolitan Water District of Southern California. Report: Water Surplus and Drought Management: Attachment 1 2015 WSDM Storage Detail. April 14, 2015). Met member agencies also have significant underground reserves.
20. The Santa Clara Valley Water District has shelved its plan to ship supplies north from storage in Kern County for the time being. (P. Rogers, "California Drought: Plans to Make State Water Project Flow Backward Shelved for This Year," *Mercury News*, May 4, 2015). But in June 2015, the City of Tracy and some agricultural districts began pumping water north from the San Luis Reservoir through the Delta Mendota Canal (G. Warren, "Emergency Drought Project Reverses Flow in Delta-Mendota Canal," KXTV Sacramento, June 30, 2015.)
21. See the discussion of electricity in the technical appendix. California's dependence on hydropower has significantly declined over time, from more than 30 percent of electricity use in the 1960s to an average of just 12 percent since 2000. The supply of other renewables (solar, wind) has tripled in recent years. Thermal power plants have been reducing water use and transitioning to recycled water since the early 2000s, and recent efforts have focused on reducing vulnerability for plants dependent on unreliable surface water sources.
22. H. McCann and C. Chappelle, "Drought Bills: Small Changes, High Impact" (PPIC blog, June 30, 2015).
23. See the discussion of urban water utilities in the technical appendix. The fiscal challenge for utilities arises because the majority (typically 70-80%) of their costs are fixed, while a similar proportion of their bill is variable, tied to the volume of water sold. The estimate of net revenue losses is from S. Moss et al., *Executive Order B-29-15 State of Emergency Due to Severe Drought Conditions Economic Impact Analysis* (M. Cubed, 2015); it excludes the losses from voluntary conservation already achieved before the mandate went into effect.
24. The case involves tiered water rates in the City of San Juan Capistrano. See the discussion of urban water utilities in the technical appendix.
25. E. Hanak, "The High Cost of Drought for Low Income Californians" (PPIC blog, June 18, 2015).
26. This is especially true for businesses that have already made significant investments in reusing processing water, for instance. For a review of potential impacts of the drought on water-sensitive activities, see the discussion of nonfarm economic impacts in the technical appendix.
27. The conservation tiers for each community were set based on per capita residential use, but the target it is being applied to total urban water use.
28. See the discussion of water markets in the technical appendix, including Figure A5 on market trends.
29. See J. Mount et al., *Water Use in California* (PPIC, 2014) and E. Hanak et al., *California's Water: Water for Farms* (PPIC, 2015).
30. For shifts in crop types, see Figure 3.7 in E. Hanak et al., *Managing California's Water* (PPIC, 2011). For irrigation efficiency trends, see G. Tindula et al., "Survey of Irrigation Methods in California in 2010," *Journal of Irrigation Drainage Engineering*, 2013, Vol. 139(3): 233-238.
31. See E. Hanak and E. Stryjewski, *California's Water Market, By the Numbers: Update 2012* (PPIC, 2012).
32. See J. Lund et al., "Taking Agricultural Conservation Seriously," (Californiawaterblog.com, March 15, 2011).
33. For cities and suburbs, conservation usually results in system-wide savings. Because so many Californians live in coastal areas, saving water indoors reduces outflows of treated wastewater to the ocean. And across the state, saving water outdoors by replacing turf with lower-water landscapes saves water, without reducing economic activity.
34. Data on farm impacts are from analyses done by the UC Davis Center for Watershed Sciences for the California Department of Food and Agriculture. See technical appendix Table A5 and related discussion.
35. See the discussion of water marketing in the technical appendix, including Figure A5 on market trends.
36. J. Medellín-Azuara et al., "California Drought Killing Farm Jobs Even as They Grow" (Californiawaterblog.com, June 8, 2015).
37. For long-term loans, banks are requiring farms to have multiple water sources—not just groundwater. This should limit the expansion of new orchards onto non-irrigated ranchland.
38. Little information is available on the costs of subsidence in agricultural areas. Examples of local infrastructure damage described above (see note 12) suggest these costs may not always be very high—e.g., $2.5 million for a bridge repair, $10 million for conveyance changes from a local reservoir—in part because these areas are not as built up as cities.
39. Such ordinances should be temporary, in anticipation of the adoption of sustainable pumping rules under SGMA. Because the rights to use groundwater in California are not based on seniority, but rather on ownership of land overlying the basin, it does not necessarily make sense for local agencies implementing SGMA to give priority to those with existing wells. Instead, they may wish to apportion pumping rights based on acreage, irrespective of the volumes current being pumped. Either way, a cap and trade system, which facilitates the trading of pumping rights within the basin, can help lessen the overall costs of implementation.

40. For fishing and water-based recreation, see the discussion of nonfarm economic impacts in the technical appendix.
41. For a discussion of drinking water quality issues in rural communities, see E. Hanak et al., *Paying for Water in California* (PPIC, 2014) and T. Harter et al., *Addressing Nitrate in California's Drinking Water with a Focus on Tulare Lake Basin and Salinas Valley Groundwater.* Report for the State Water Resources Control Board Report to the Legislature. (Center for Watershed Sciences, University of California, Davis, 2012).
42. See discussion of drought-related public health issues in the technical appendix.
43. For the state, this includes the State Water Board, the Department of Water Resources, the Department of Housing and Community Development, the Office of Emergency Services, and the Governor's Office of Planning and Research. County officials are also involved, as well as local non-profits and in some cases nearby water districts.
44. There are legal constraints to providing state funding to directly invest in private property improvements.
45. Recent reforms include the creation of a special office within the State Water Board to support funding for disadvantaged communities and legislation that authorizes the board to require consolidation of small systems. Proposition 1, the new water bond, also contains more than $500 million for small rural water and wastewater systems. State and federal funds are typically restricted to covering capital costs, whereas some systems will also need support for operations. See E. Hanak et al., *California's Water: Paying for Water* (PPIC, 2015). The new law that makes well logs public (Senate Bill 83, June 2015) should also help, because it makes it possible to project likely areas where wells will go dry with falling groundwater levels. This information will be useful for well owners and for focusing emergency state support.
46. See chapter 5 of E. Hanak et al., *Managing California's Water: From Conflict to Reconciliation* (PPIC, 2011).
47. One exception is wetlands, where groundwater can replace lost surface flows.
48. Other species are also vulnerable, including many terrestrial animals and plants. For most species, including some of the populations discussed in the text, the state lacks sufficient monitoring information to either gauge drought impacts or guide management.
49. See Central Valley Joint Venture, accessed July 9, 2015.
50. Managed wetlands account for a relatively small share of water use in California: typically 1.5 million acre-feet, or less than 2 percent of the total (J. Mount et al., *Water Use in California*, PPIC, 2014).
51. N. Seavy et al., "Farms That Help Wildlife," (PPIC blog, April 21, 2015) and J. Mount et al., *California's Water: Water for the Environment* (PPIC, 2015).
52. Rice acreage fell from an average of 567,000 acres in 2010–13 to just 434,000 acres in 2014 (-24%), and acreage in 2015 is projected at 385,000 (-32%) (US Department of Agriculture, National Agricultural Statistics Service, California Acreage Reports, accessed July 28, 2015). Tight water conditions are also reducing the acreage that gets flooded post-harvest.
53. The Nature Conservancy California, "Precision Conservation," accessed July 9, 2015.
54. The program is called the Critical Waterbird Habitat Fund Pool. Whereas the BirdReturns program uses an auction to determine payments, the NRCS program makes fixed payments.
55. Personal communication, Jay Ziegler, The Nature Conservancy, July 8, 2015.
56. Unpublished modeling work, Ducks Unlimited. This modeling was specific to ducks and geese, but the shortfall in habitat could impact shorebirds as well.
57. P.B. Moyle et al., "Rapid decline of California's native inland fishes: a status assessment." *Biological Conservation*, 2014, Vol. 144(10): 2414–2423; P.B. Moyle et al., "Climate change vulnerability of native and alien freshwater fishes of California: a systematic assessment approach," *PLoS One* 2013; and P.B. Moyle et al., *Fish Species of Special Concern in California*. Sacramento: California Department of Fish and Wildlife, 2015.
58. This includes periodic curtailment of diversions on Antelope Creek and Deer Creek since 2014 to support spring-run Chinook salmon, and recent orders to stop groundwater use on landscapes on several creeks in the Russian River watershed to support coho salmon and steelhead.
59. J. Mount, "Better Reservoir Management Would Take the Heat Off Salmon" (PPIC blog, June 23, 2015).
60. See technical appendix TableA9 and related discussion for a list of the species, the methodology used for this assessment, and a discussion of potential management actions.
61. C. Chappelle and L. Pottinger, "California's Streams Going to Pot from Marijuana Boom" (PPIC blog, July 23, 2015).
62. The development of native fish-oriented flow regimes below many dams would also be beneficial. See T. Grantham et al., "Systematic screening of dams for environmental flow assessment and implementation," *Bioscience*, 2014, Vol. 64: 1006–1018.
63. Some species are already kept in captivity with the goal of preventing extinction (such as delta smelt, Central Coast coho salmon, McCloud River redband trout, and Central Valley winter-run Chinook salmon). The use of conservation hatcheries will be more difficult for fish that do not already have captive populations or populations that live outside of their native range. See technical appendix Table A9 and related discussion.
64. For some fishery sector statistics, see technical appendix Figure A8 and related discussion.
65. P.J. McIntyre et al., "Twentieth-century Shifts in Forest Structure in California: Denser Forests, Smaller Trees, and Increased Dominance of Oaks," *Proceedings of the National Academy of Sciences*, 2015, Vol. 112(5): 1458–1463.
66. The federal government owns 55 percent of forests and woodlands in California (California Department of Forestry and Fire Protection: Forest and Rangelands 2010 Assessment). On permitting challenges on federal lands, see M. North et al., "Constraints on Mechanized Treatment Significantly Limit Mechanical Fuels Reduction Extent in the Sierra Nevada," *Journal of Forestry*, 2014, Vol. 113(1): 40–48.
67. See E. Hanak et al., *Paying for Water in California* (PPIC, 2014).
68. The Center for Irrigation Technology at Fresno State University estimates that only about a third of wells are now metered; such metering can be useful for efficient on-farm water use as well as groundwater basin management. See the interview with David Zoldoske in L. Pottinger, "The Challenges of Getting More Crop per Drop," (PPIC blog, July 28, 2015).

69. See the discussion on water markets in the technical appendix.
70. Some promising recent changes in this direction include new reporting and measurement requirements for surface water diversions. See H. McCann and C. Chappelle, "Drought Bills: Small Changes, High Impact" (PPIC blog, June 30, 2015).
71. One promising approach to environmental drought planning comes from Australia. See J. Mount et al., *Policy Priorities for Managing Drought* (PPIC, 2015).

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