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Inaction's Economic Cost for California's Water Supply Challenges

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California's water system is in for challenges in coming decades as climate, groundwater policy, and environmental regulations reduce availability and increase variability in water supplies for agricultural and urban uses. A previous report estimated 4 to 9 million acre-feet (maf) per year of unavoidable reductions in existing water supplies, 12% to 25% of today's water use (Lund et al. 2024). This report estimates the economic costs of not responding to these reductions in water availability, summarized in Table 1.

Table 1: Economic Losses to California from Likely and Worse Future Scenarios

Scenario	Water loss description	Statewide direct economic losses ($B/y)			Statewide Direct, Indirect, & Induced Losses**($B/y)
		Urban	Ag & linked sectors*	Total direct	
Base 2020	No change from 2002-2020	0.0	0.0	**0.0**	**0**
Likely Future	**5 maf**: Sac Valley 1.5 maf, SF Bay + Southern Central Valley 3 maf, S. Cal 0.5 maf	0 - 2.2	1.8– 2.2	**1.8 - 4.4**	**3.4-6.4**
Worse Future	**9.5 maf**: Sac Valley 2.5 maf, SF Bay + S. Central Valley 5.5 maf, S. Cal 1.5 maf	0 - 6.5	3.7-4.6	**3.7-11.1**	**7.0-14.5**

*Direct agriculture impacts include value added losses in crops, animal products, and food and beverage processing, which depend on crops.

**Includes Statewide multiplier effects of value added from agriculture and linked economic sectors, and direct urban welfare losses from water shortages. More details are in Tables 6 and 7 in Section 5.

California gross domestic product (GDP) impacts on urban, agriculture, and related sectors range from $1.8 billion to $11.1 billion per year, depending on any shifting of water from less to more valuable uses by markets, agreements, or policies. Statewide total (multiplier) effects of a worse future could be as high as $14.5 billion per year in value added (GDP), including losses in urban and community users' welfare, agriculture, and linked sectors. Impact estimates of this study exclude utility revenue losses from reduced water sales and industrial shortages, which are much less common.

Long-term water shortage costs for California's three largest water-use regions, Southern California, the Bay Area and southern Central Valley, and the Sacramento

Valley were developed. For each region, recent annual water availabilities were modeled and paired with models of economic value of water use in agriculture and cities. Water availability distributions were then shifted for future conditions to estimate future agricultural and urban water shortage costs without additional management and investments.

Some investments to expand supplies and reduce demand will be worthwhile - especially to mitigate urban shortages and high-value agriculture - while others might be more expensive than their water supply benefits. These potential economic losses are large enough to motivate organized state, regional, and local policy and planning discussions.

Managing water in California is always costly and controversial. State government leadership has historically been vital for organizing and preparing for long-term water challenges. **Renewed state leadership would certainly help in organizing and implementing collective preparation for this future.**



California's water system will see major challenges in the coming decades. Changes in groundwater policy, climate change, and environmental regulations will reduce the water available for agricultural and urban uses. These reductions will also increase variability in water supplies. A previous report (Lund et al. 2024) examined and roughly quantified these seemingly unavoidable changes, summarized in Table 2.

Table 2: Expected major changes in California water supplies (Lund et al 2024)

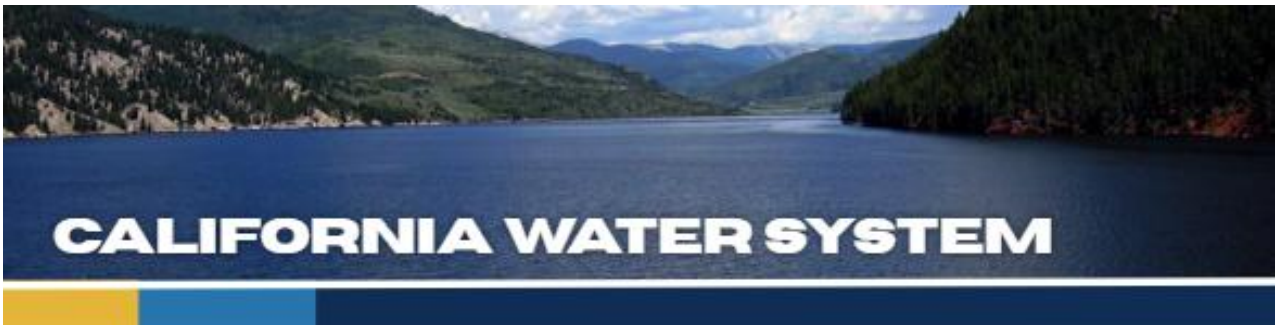
Change	Estimated Average Loss Quantity	Description
Ending groundwater overdraft	2-3 maf/year	SGMA requires eliminating groundwater overdraft by 2040
Reduced Colorado River supplies (California's share)	0.5-0.8 maf/year	Address historical imbalance of 1.5-2.5 maf/yr in lower Colorado River Basin supplies and demands, plus climate change reductions
Climate change	1-3 maf/year	Warmer climate increases evaporation and shifts flows to winter, which are harder to capture
Increased environmental flows	1-2 maf/year	Anticipated increases in statewide environmental flows (especially in non-winter months)
Other supply losses	0.1- 0.2 maf/year	Aquifer salination, effects of reduced conveyance and storage capacities due to subsidence, water quality impairment, etc.
Total #	**4.6 - 9 maf/year**	**For context, this quantity is roughly 1.5-3 million acres of irrigated land, or 50-90% of urban water use**

The likely total range is nearer the middle of this range of summed minimum and maximum range since it is unlikely that everything goes well or poorly.

This report examines the economic costs of not responding to these reductions in water availability.

California has adapted its water system to many major changes in the past. Although water supplies today have never been more abundant, reliable, and safe for human water use, agricultural and environmental water shortages remain chronic in most years and can become acute for all sectors in extreme droughts. More people and a larger economy rely on this water system, and native ecosystems have never been more endangered. Water managers, regulators, users, infrastructure, and policies need to prepare for major changes and worsening conditions.

This report begins with a brief overview of California's water system, followed by discussions of its future water supplies and demands, California's economic dependence on water supplies and the portfolio of actions available for managing future water shortage conditions. Potential economic impacts of likely future water shortages without further improvements are then estimated, followed by a discussion of policy and management implications, and conclusions. A short technical appendix presents more results and methodological details.



Water management in California is unusually complex, reflecting California's large size, complex hydrology, water demands, and infrastructure, and de-centralized multi-layered management with many coordinating laws, regulations, contracts, and agreements. Thousands of local, regional, state, and federal institutions develop, manage, and regulate this water system for diverse and sometimes divergent purposes. In California, it is very difficult for independent actions, even by State or Federal governments, to be effective without intergovernmental and local coordination.

Local, regional, state, federal, and private institutions have developed, own, operate, and regulate California's extensive and diverse infrastructure, depicted in Figure 1, to move water from streams and aquifers to areas with large water demands or water storage capacity at desired times of year and for droughts.

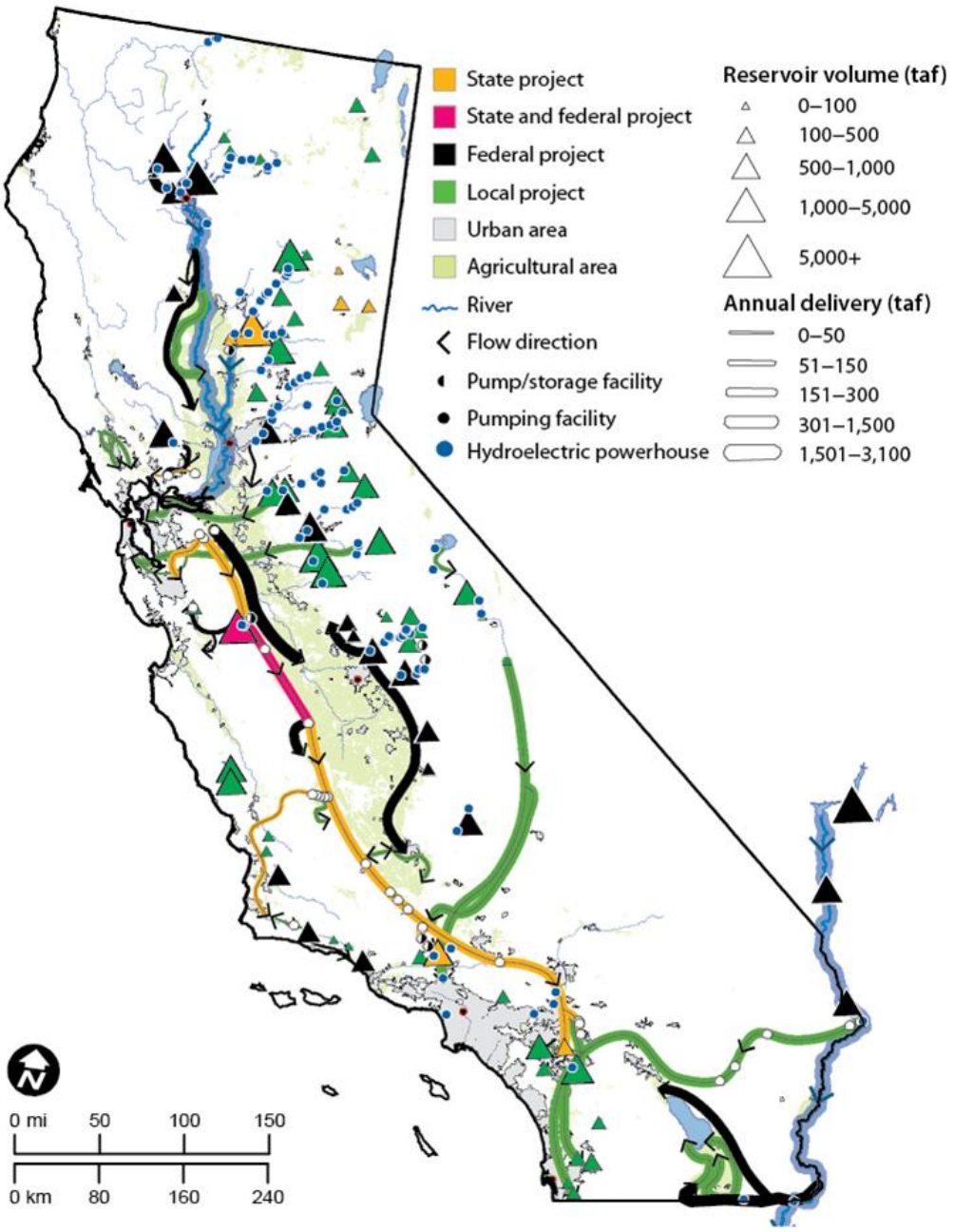


Figure 1. Major California water management infrastructure (Hanak et al. 2011)

Each of the dozens of state and federal agencies and thousands of local and regional agencies has its own missions, responsibilities, decisions, and often its own infrastructure. Altogether, the process of finding and capturing water, treating it, moving it, and storing and operating it to serve a variety of water demands constitutes a water supply management portfolio. Elements of such portfolios are summarized in Table 3 and work together to improve the reliability, cost, and quality of water deliveries.

Decision-makers in California's water supply system range from providers of wholesale and retail water, providers and operators of infrastructure, water regulators, and millions of water users. In a system this large, diverse, interconnected, and complex, local, regional, and statewide users benefit most when each component is coordinated and managed to work together. An effective water management portfolio usually includes actions that help the many users and institutions work together, using economic incentives, legal/political requirements, and social/information means.

Table 3: Water supply system portfolio elements

Water Supply		
Water Sources – Capture of precipitation, streams, groundwater, wastewater, purchased water; Protection of source water quality		
Conveyance – Rivers, canals, pipelines, aquifers, tankers (sea or land), bottles, etc.		
Storage – Surface reservoirs, aquifers and recharge, tanks, snowpack, etc.		
Treatment – Water and wastewater treatments, wastewater reuse, ocean desalination, contaminated aquifers		
Operations – Reoperation of storage and conveyance; Conjunctive use		
Water Demands		
Agricultural use efficiencies and reductions	Ecosystem demand management	
Urban use efficiencies and reductions	Recreation water use efficiencies	
Working Together		
Economic	**Legal/Political**	**Social/Information**
Pricing Markets Subsidies, Taxes Insurance	Water rights Contracts State, federal and local regulations	"Norming", shaming Education Information Conversations

Keeping California's decentralized system balanced and accountable to its various missions and interests requires feedback and accountability among various levels of decision-making, from state/national to utilities to water users.

California's water system's diversity and complexity gives it extensive adaptive capacity to work through reductions in water supply availability from many sources, albeit at sometimes considerable expense and delays. Making adaptation work often requires state and regional leadership.



California's water system will be challenged by increasing climate extremes and water supply volatility, along with intensifying water demands and regulatory constraints for groundwater and ecological sustainability. Lund et al. (2024) estimate water shortage increases ranging from 4.6 to 9 million acre-feet annually, due to a combination of existing and emerging interconnected factors (Table 2).

Climate Change. Warmer temperatures reduce snow precipitation, accelerate snowmelt, shrink snowpack, and increase evapotranspiration to reduce water availability. The recent 2020-2022 and 2012-2016 droughts were among the warmest periods in the instrumented record (Medellin-Azuara et al. 2022).

Groundwater overdraft. The 2014 Sustainable Groundwater Management Act (SGMA) will force reductions in groundwater pumping mostly for irrigation in the San Joaquin Valley. From 2 to 3 million acre-feet of water historically used for irrigation, will likely become unavailable with SGMA's required balance of recharge and extractions by the early 2040s.

California Allocation from the Colorado River. The Colorado River system is facing declining reservoir levels from evapotranspiration and excessive deliveries relative to inflows. This will likely force cutbacks to the seven states and Mexico to balances use with supplies, rebuild reserves, and secure hydropower generation and future water supplies. Overall Colorado basin reductions probably need to be 1.5-2.5 million acre-feet per year. For California, 0.5 to 0.8 million acre-feet per year reductions are likely.

Environmental Flows. The ecosystems in the Sacramento-San Joaquin Delta need sufficient outflow to deter salinity that compromises water quality for both protected species and human water supplies and reduce fish mortality in and near water export facilities. This might be achieved by modifying upstream and in-Delta diversions. Sea level rise may also increase required Delta outflows. Temperature controls for salmon further constrain water availability for irrigation in late summer, which will likely be

exacerbated by climate change. A 1 to 2 million acre-feet/year reduction in water availability is likely from these changes.

In response to future declining water supplies, California's water use will need to adapt in several ways, including various forms of water supply augmentations, demand management, and government and policy innovations (Table 3).

Capturing Additional Flows. Increased capture of surface water surplus in non-dry years through surface reservoirs or managed aquifer recharge can make some more water available, especially for dry years. However, costs, permitting, and the limited frequency of available water hinder many aquifer recharge and reservoir projects.

Water Reuse and Recycling. Although reused or recycled urban water supplies remain a small proportion of California's water supply portfolio, technological improvements may reduce their cost and can help expand urban water supplies.

Demand Management. Increased irrigation efficiency, changes in cropping patterns, and land idling are common strategies to reduce applied water demand in irrigated agriculture. Nevertheless, reduced consumptive use is not achieved in some cases due to expanded or intensified irrigated areas or reduced groundwater recharge. Conservation in urban areas, particularly in outdoor use, usually achieves the largest urban water savings, although it can place a high financial burden on local urban water agencies, depending on their financial structure.

Water Markets. Water markets can often reduce shortage water costs by the exchange of water among users locally and across regions. Water scarcity increases the opportunity cost of water, incentivizing willing water sellers and buyers to exchange. Considerations of distributional effects of transfers, transaction costs, environmental impacts, third-party externalities, and institutional constraints may dampen the feasibility of water markets. Overall, regional water markets may substantially reduce costs of shortage from climate or regulation.

Groundwater Management. The development of groundwater extraction in the early 1900s in California as an alternative to surface water due to drought or lack of irrigation delivery infrastructure or surface water rights, brings groundwater overexploitation, especially in southern Central Valley. The 2014 Sustainable Groundwater Management Act incentivizes local organizations to plan and implement for balancing recharge and extraction by the early 2040s. Although SGMA will likely improve local groundwater supplies for drought, reductions in consumptive use are needed and most likely will come from sizable permanent idling or repurposing of irrigated lands.

Environmental Resilience. With diversions and total water use at historic highs and a more volatile climate, ecosystems' ability to thrive is diminished. During the recent droughts (2012-2016 and 2020-2022), some fish came to the brink of extinction.

Infrastructure is operated under an extremely complex and constrained system, that considers minimum streamflows, and water quality considerations in deciding water allocations. Yet these measures are often insufficient to prevent chronic declines in native species. Some measures to provide compensation for conserving water for the environment may facilitate securing water for native species.

California's water supply systems must contend with many changes, with overall reductions in traditional water supply availability. California's water management institutions, including its major retail and wholesale utilities, which have a history of effective adaptations to change, will nonetheless find these changes to be challenging without regional and statewide coordination and support.



This section examines the direct and spillover regional economic costs for several water availability scenarios for California's three largest regions (Sacramento Valley, San Joaquin Valley and San Francisco Bay, and Southern California) and two largest water use sectors (agriculture and urban). The analysis begins with water availability, use, and its direct economic value today. Then three levels of future reductions in statewide water availability are examined, with several scenarios of how such reductions might be managed. Direct economic water shortage costs are compared for seven shortage magnitude and management scenarios. The results also include additional effects on employment, gross revenues and value added.

Estimated water availability, use, and direct economic value today

For this analysis, we represent the yearly likelihood of different amounts of water being available based on historical water deliveries and urban and agricultural use in three regions, the Sacramento Valley, the San Joaquin Valley and Bay Area, and Southern California. These DWR water portfolio data are from 2002-2020 (excluding 2017, a wet year, which was unavailable). These represent the as-delivered annual water available for users in these regions over these years, after storage and conveyance operations. These quantities incorporate operations to supplement droughts with surface and groundwater storage and were fit to log-normal probability distributions so more severe water availability conditions are represented (as described in the Technical Appendix C). These historically based water availability distributions appear in Figure 2.

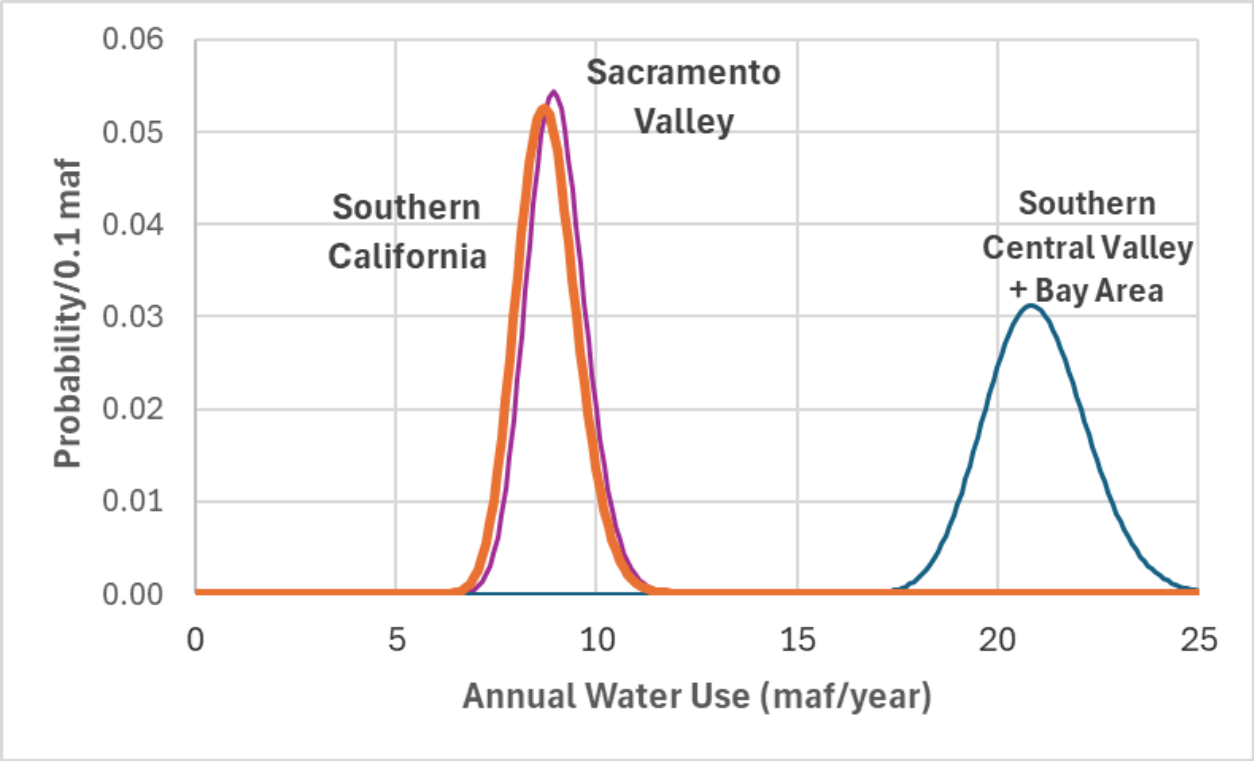


Figure 2. Estimated recent distribution of water availability for use in three major regions of California

From a wide range of recent technical studies, the economic value of these variable regional water supply availabilities today can be estimated, as described in the Technical Appendix A. The direct economic values of water delivery for urban and agricultural users in these three regions are summarized in Figure 3 below.

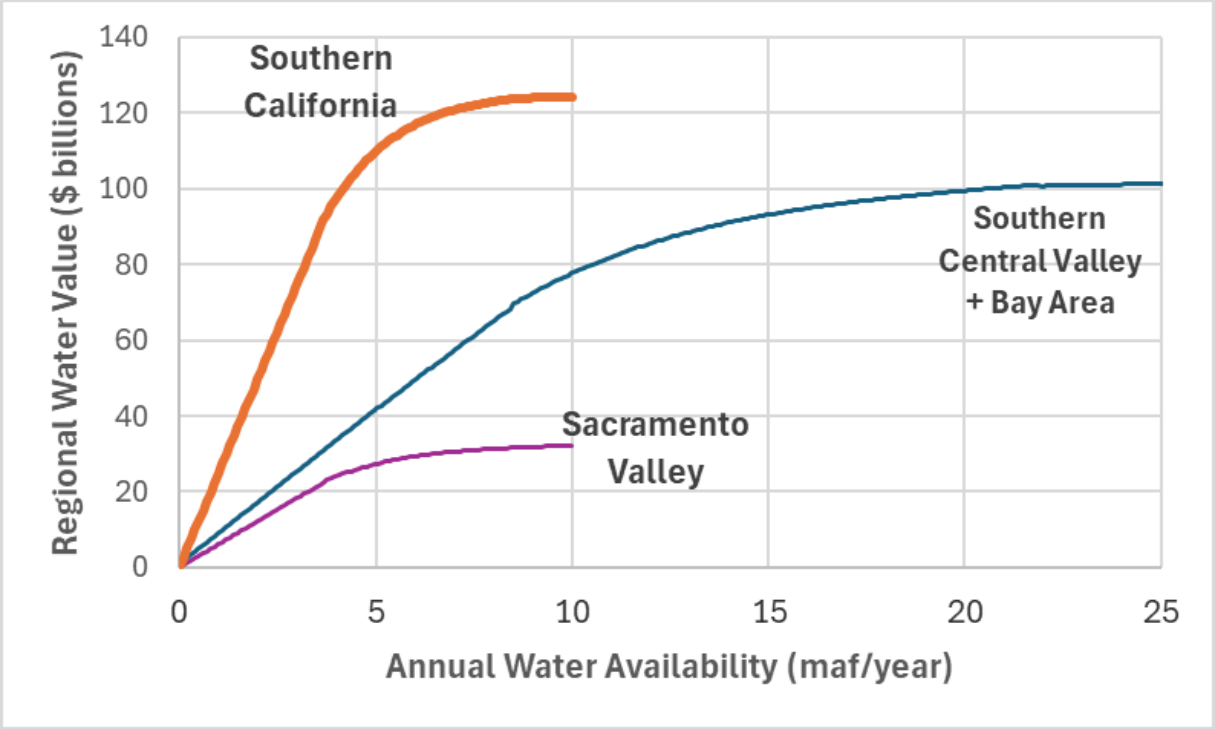


Figure 3. Estimated direct annual economic value of water use today in three major regions of California varying with water availability

In all cases, the first quantities of water delivered have the greatest economic value, as these tend to be employed for the most economically valued water uses (i.e., delivering water to more profitable crops before irrigating less profitable crops). The high economic value of most urban uses (i.e., dollars per unit of water relative to many agricultural uses) means that for all regions, the greatest economic value usually comes from the first 25% of regional water use. Overall, in all regions, agriculture is responsible for less than 25% of all water value, despite using 89%, 87%, and 51% of all urban and agricultural water use in the Sacramento Valley, SJV + Bay Area, and Southern California regions, respectively.

Table 4 summarizes the overall economic value of water in California's economy for the two most economically important sectors and three most important regions of California.

Table 4. Estimated average direct economic value of water use in California today ($ Billions/year)

	North of Delta	SJV + Bay Area	Southern California	Total
Urban Value	27.83	75.94	119.70	223.5
Agricultural Value	3.94	24.14	3.88	32.0
Regional Total	31.8	100.1	123.6	255.4

In later sections, we modify the quantities of water available for several future condition scenarios—based on the potential restrictions shown in Table 2—and estimate the direct economic losses regionally and statewide from water availability and management changes.

Future water availability

We developed several scenarios for changes to future water availability in California, based on our earlier work and that of others (Lund et al. 2024; Escriva-Bou et al 2023; Schmidt et al. 2023; SWRCB 2023), summarized in Table 2 above. These cuts will modify the probability distributions presented in Figure 2 by reducing availability uniformly to both wet and dry years. For our cost analyses here, we examine three levels of water availability loss statewide of No change, Likely future (5 maf/year loss), and Worse future (9.5 maf/year loss), summarized in Table 5 below.

Table 5: Three Water Availability Change Cases, million acre-feet of lost water availability

Change	No change	Likely future	Worse future
Ending groundwater overdraft	0	2	3
Reduced Colorado River supplies	0	0.5	1
Climate change	0	1.5	3
Increased environmental flows	0	1	2
Other supply losses	0	0	0.5
Total	**0**	**5**	**9.5**

As summarized in Table 6, different scenarios are analyzed to show how three different shortage levels are allocated across regions and between major water use sectors.



We developed a model of the costs of water shortage scenarios for California's three largest water-use regions, Southern California, the Bay Area and southern Central Valley, and the Sacramento Valley today. For each region, the recently experienced frequency of water availability was paired with models of the direct economic value of water use in agriculture and cities. Rising values for future water use would raise these costs.

The distributions of water availability were then shifted among regions and between major sectors for different future water availability scenarios to estimate resulting future water shortage costs for each scenario. These water availability reductions and direct crop revenue losses for agriculture (without other related sectors) and welfare losses for urban uses for each scenario are summarized in Table 6 (with more details in Appendix Table D-1).

Table 6: Larger Variety of Likely Future and Worse Future Scenarios and Statewide Economic Losses for each Sector

	Scenario	Water loss description	Statewide economic loss ($B/y)		
			Urban	Agriculture	Total
0	**Base 2020**	No change from 2010-2020	0.0	0.0	**0.0**
1	**Likely Future**	**5 maf** losses: Sac Valley 1.5 maf, SF Bay +Southern Central Valley 3maf, S. Cal 0.5 maf, with urban share same as 2010-2020	2.2	2.1	**4.3**

	Scenario	Water loss description	Statewide economic loss ($B/y)		
			Urban	Agriculture	Total
2	**Likely future, All losses to agriculture**	**5 maf** losses: Sac Valley 1.5 maf, SF Bay + Southern Central Valley 3 maf, S.Cal 0.5 maf, all agricultural reductions	0.0	2.7	**2.7**
3	**Worse future**	**9.5 maf** losses: Sac Valley 2.5 maf, SF Bay + Southern Central Valley 5.5 maf, S.Cal 1.5 maf, with urban shares same as 2010-2020	6.5	4.5	**10.9**
4	**Better worse future**	**9.5 maf** losses: Sac Valley 2.5 maf, SF Bay + Southern Central Valley 5.5 maf, S.Cal 1.5 maf, most reductions go to agriculture	2.3	5.1	**7.4**
5	**Worse future, All losses to agriculture**	**9.5 maf** losses: Sac Valley 2.5 maf, SF Bay + Southern Central Valley 5.5 maf, S.Cal 1.5 maf, all agricultural reductions	0.0	5.6	**5.6**
6	**Each sector loses 1 maf in each region**	**6 maf** losses, 1 maf loss to each sector and region #	38.2	1.3	**39.5**
7	**Each sector loses 0.1 maf in each region**	**0.6 maf** losses, 0.1 maf loss to each sector and region	0.69	0.09	**0.8**
	#1 maf urban loss from Sacramento valley exceeds all that region's water use, so losses are immense.				

Estimated Spillover Effects from the Direct Economic Losses

Urban effects

Our analysis estimated the residential welfare losses from water shortages, a common practice in estimating economic costs of urban drought. However, other urban users, such as commercial and industrial water users, are the backbone of California's economy. At the statewide level, the share of water use by commercial and industrial users is so small, and their potential shortage costs so high that water managers tend to protect these essential economic uses during droughts. During the 2012-16 and 2020-22 droughts, no major significant economic costs were reported (see for instance Hanak et al, 2015 and Lund et al 2018), and even during the tougher 1987-92 drought, anecdotal evidence suggested that actual industrial drought impacts were small (Dixon et al, 1993).

While the statewide economy is resilient to droughts, some cities are more vulnerable to water shortages. These cities, usually having less access to a diversified water portfolio from the statewide water network, could face large economic costs if the water shortages impact essential commercial and industrial water uses. For example, during the 2020-22 drought some cities in the Russian River watershed relying on Lake Sonoma and Lake Mendocino experienced water cuts up to 50% compared to pre-drought use. Similarly, Southern California communities that rely heavily on the drought-challenged State Water Project—especially in Ventura County and east of Los Angeles—adopted major restrictions in 2022 due to reduced SWP supplies.

Although our assumption of estimating the economic cost of reduced water availability in cities by estimating residential shortages will apply in most of the state, it would be important to develop a more in-depth analysis of commercial and industrial vulnerability at the local level to ensure the resilience of California's economy during droughts. These costs, even if unimportant at the state level, could be significant locally.

Agricultural effects

The direct economic impacts of water shortages have additional spillover effects on regional economies, in terms of gross revenue (output), value added, and employment, both on suppliers of goods and services to agriculture and sectors that rely on agricultural commodities such as animal products and food processing. Water shortages affect farmers directly, as well as each input supplier (including workers) and commodity users (such as food processors) who see reduced revenues, and overall reduced demands for goods and services in the economy. These are known as "multiplier effects."

Major water using sectors, like agriculture, supply industries such as animal products, food processing and beverages. Reduced crop production limits food processing and animal products such as beef and dairy, in the absence of feasible imports or other substitutes for lost local crop production. Such additional losses can be substantial (Escriva-Bou et al. 2023).

Table 7 below provides estimates of indirect impacts for the water shortage scenarios.

Table 7: Broader Agricultural Losses, including animal products, food and beverage processing for the Larger Variety of Scenarios.

	Scenario	Direct ($B/y)			Total ($B/y)		
		Jobs (1000/y)	Output	Value Added	Jobs (1000/y)	Output	Value Added
0	**Base 2020**	No change	No change	No change	No change	No change	No change
1	**Likely Future**	9.3	4.2	1.8	**24.3**	**7.0**	**3.4**
2	**Likely future, All losses to agriculture**	13.1	4.9	2.2	**32.8**	**8.8**	**4.2**
3	**Worse future**	19.9	8.5	3.7	**51.5**	**14.5**	**7.0**
4	**Better worse future**	23.1	10.2	4.2	**59.3**	**16.6**	**8.0**
5	**Worse future, All losses to agriculture**	27.1	10.4	4.6	**67.5**	**18.4**	**8.8**
6	**Each sector loses 1 maf in each region**	7.6	2.1	1.0	**17.8**	**4.2**	**2.0**
7	**Each sector loses 0.1**	0.5	0.2	0.1	**1.3**	**0.3**	**0.1**

	maf in each region						

The first three columns of Table 7 show estimates of the augmented direct impact of agricultural water shortages including animal products and food processing. Such impacts range from $0.1 billion/year in value added (GDP), when agriculture and urban sectors share small shortages, to $4.6 billion/year under Scenario 5 (column 4), with 9.5 maf in shortage all allocated to agriculture. Other direct impact measures to agriculture and related measures include employment (ranging from 500 to nearly 27 thousand direct jobs in column 2), and gross revenues (output, column 3) measuring gross sales, range from $0.2 billion for a small shortage to $10.4 billion in Scenario 5 when all shortages go to agriculture.

When considering total potential impacts, including spillover indirect impacts to sectors suppling goods and services to agriculture, animal products, and food and beverage processing, as well as the second-round effect of reduced income from all these sectors and statewide demand for goods and services, impacts on total value added (last column) range from $0.1 billion to $8.8 billion per year. The effects on total jobs (column 5) range from 1.3 to 67.5 thousand jobs. To avoid double counting the cumulative impacts of other sectors to agriculture, we employ value added above rather than sector output ($0.3 to $18.4 billion, next to last column), which carries value from upstream sectors.

Extensive land idling can bring major challenges for agriculture-dependent regions, particularly in California's Central Valley, with fewer off-farm employment opportunities for lower-income groups and threaten the long-term viability of these communities. Reduced availability of crop and animal products may impact food and beverage processing industries, which rely on consistent input supplies to cover fixed costs and remain economically viable.

Some observations

1. Small shortages cause much smaller costs, as cities and farms manage to cut non-essential water uses. But larger shortages have increasingly larger costs: doubling water cuts (from scenarios 1 to 3), more than doubles economic losses.

2. The distribution and management of water losses to different regions and sectors can have an even more economic impact than the overall volume of water availability lost. Moving from allocating water cuts based on historical proportions on cities and farms to allocating all additional scarcity to agriculture reduces statewide direct economic losses by 37% when water cuts are 5 maf/yr (comparing scenarios 1 and 2) and by more

than 50% (comparing scenarios 3 and 5) for 9.5 maf/yr. Shifting losses across regions can also redirect economic losses and reduce them overall. Such changes might occur by various state or regional allocation mechanisms or water market policies to allow shortages to shift to the least profitable sectors and regions with market compensation or regulations.

3 Spillover effects of water shortages may bring challenges regionally and statewide. Spillover effects for agriculture are likely to be larger as reductions in crop production reduce overall demand of production factors for agriculture, and also availability of agricultural commodities for the livestock sector, food and beverage processing that requires volume of production to be economically viable. This amplifies the impact on the overall economy beyond primary direct losses in agriculture. Well-managed urban water shortages tend to be mostly to households with high consumer surplus losses, but lesser multiplier effects.

4 There are immensely greater direct economic losses from incremental water losses to urban areas than agricultural sectors in all regions (Table 4, Scenarios 6 and 7). This is despite important variability in incremental economic losses within each sector such as from different agricultural crops and businesses and different urban uses (especially landscape irrigation and indoor uses). However, economic losses to rural agricultural communities can be especially threatening for these local and regional economies.

5 There are important differences in incremental agricultural losses across regions. Although all regions have some very profitable crops and agricultural activities, more of these are present in the southern Central Valley (Bay Area + SJV region), making agricultural economic losses there generally steeper than in other regions. North of the Delta, the Sacramento Valley tends to have the lowest incremental direct economic losses. Regional differences in urban incremental costs shown here are not very important, partly because urban uses are small in the Sacramento and Southern Central Valley regions.



Prudent management of shortages can usually mitigate statewide impacts considerably, although local conditions can be much more severe. The recent droughts highlight both California strengths and weaknesses for weathering water scarce conditions. A combination of systemic flexibility in water allocation and use, modernizing institutions and regulation to enhance and incentivize accounting, water trading and managed aquifer recharge, and additional infrastructure will need to work in concert to adapt to water challenges through timely planning and effective responses at local, regional, and statewide levels. Estimates from this study assume minor transaction costs and efficient management and allocation within existing infrastructure. But economically worthwhile management alternatives are sometimes politically or institutionally delayed, costly, or simply infeasible.

Utilities, particularly in urbanized areas, have for decades used portfolio approaches to increase water supply reliability through a mix of water conservation, reuse and recycling, desalination, groundwater banking, water markets, and water rationing in extremes. State conservation mandates have been achieved by most cities, largely due to a relatively high proportion of outdoor urban water use. However, conservation has affected utilities' revenues as most costs are usually fixed, but revenues vary more with water sales (Lund et al. 2018).

Agriculture tends to have a more limited portfolio dominated by increased groundwater pumping in drier years. Other forms of adaptation include idling land on less profitable field and grain crops (e.g. rice and cotton) and acquiring water from carryover storage or market transactions to continue irrigating permanent or more profitable crops, or sometimes opportunistically removing trees nearing their productive life span. Water conservation via low volume irrigation methods have not always reduced net (consumptive) use at the basin scale, due to irrigated area expansions and reduced aquifer recharge (Grafton et al. 2018). The onset of climate extremes, environmental and groundwater regulation will likely limit agriculture's resilience and adaptability in the absence of flexible water allocation schemes including delivery and storage, and the infrastructure of incentives to conserve and expand its portfolio of options (Medellin-Azuara et al. 2024).

Ecosystems have proved to be more vulnerable to droughts largely due to a long history of upstream surface water diversions, groundwater overuse, and water quality and habitat deterioration. Although state and federal entities have devoted

significant technical and infrastructure resources to reduce impacts of water operations on native species, such efforts have proved to be insufficient, so far. Small rural water systems also have proven to be persistently vulnerable due to historical disadvantages and having less ability to take advantage of economies of scale in technologies and organization. Rural communities have received useful state support to secure drinking water, yet a more robust strategy to reduce the need for emergency response is not in place for California's many diverse small systems.



Initiative and innovations for California's water systems have shifted over time across local, regional, state, and federal levels, accumulating infrastructure, institutions, and diversifying institutional authorities over this history. Prospects and experiences of shortages costs have always triggered investments, especially when the economic costs are high (and we are willing to mitigate). So local, regional, and statewide decision-makers should expect growing water scarcity. The question is if coordination of state, regional, and local responses can occur to better achieve lower costs as well as environmental, public health, and reliability benefits.

In the late 1800s, State Chief Engineer William Hammond Hall realized that local water management alone would be unable to manage water (supply, flooding, and mine tailings) for long-term growth, and so he set about collecting and developing regional and statewide water data and plans (Crawford & Herrick 2006). At that time, such plans and state involvement were politically doomed, mostly from local fears, one suspects. By the 1920s, it was clear to most regions that the interbasin capture and movement of water would be needed to sustain growth, following the successes of the Los Angeles Aqueduct in 1914, followed by the formation of MWDSC and construction of the Colorado River Aqueduct in 1933. The State followed in the 1920s to develop the 1930 State Water Plan, which shifted to become the Federal Central Valley Project in the 1940s to the present. Again, seeing the limits of local water infrastructure, and desiring more state and local control, the State Water Project was developed in the 1960s and 1970s as a more extensive system to store and move water statewide (Hundley 2001).

With the substantial completion of these systems, large reservoir and conveyance projects began to suffer from diminishing marginal returns, with rapidly growing financial and environmental costs and diminishing additional water supply availability. The 1976-77 drought showed that large water projects alone could not

practically provide water supply reliability. Large water projects were further stymied by the vote against the Peripheral Canal in 1982.

This led to an era from roughly 1980 to 2020 where most water management innovation and infrastructure was local and regional involving urban per-capita water use reductions, groundwater banking, wastewater reuse, often facilitated by state and federal laws, regulation (such as plumbing codes for urban conservation, and environmental regulations), and funding (without construction leadership or ownership). During this time of renewed local and regional initiatives, California's population grew by 66%, its economy grew by 950%, its total urban use stayed about the same (at 8 maf/yr), and its agricultural water use fell by about 3 maf/year (to 31 maf/year), with very little growth in inter-basin transfer infrastructure. During this period, state and federal initiatives greatly diminished.

In recent years, the state has returned to a higher level of leadership, mostly to support rural small systems, groundwater sustainability (SGMA), and native ecosystems. These are problem areas where local and regional management have often not succeeded alone.

California water seems unlikely to return to the heyday of federal and state dam construction projects. Water management and initiatives are likely to remain more local and regional than statewide or federal. State water plans might take the form of regional water plans coordinated across regions, with harmonizing (if possible) state and federal administrative and regulatory involvement. Recent mostly favorable experiences with SGMA plans suggest collaborative approaches to regional and statewide plans could be promising.

There are some areas where state and federal governments will remain and become important, and potentially valuable to support long-term resilience of the water, environmental, and economic systems. These likely include state legal support for water rights, water accounting, contracts, and enabling legislation, some federal and state technical support for common data and modeling, regulatory reform, and some facilitative funding contributions for statewide interests for regional efforts, rural communities, and environmental objectives.

Preparing state and federal ecosystem regulations and operations for climate change with higher temperatures, sea levels, and shifts in species composition will be especially vital and challenging and require sustained state-level support and coordination. This seems essential for improving the operations of existing infrastructure and making any new storage and conveyance infrastructure effective and viable for urban and agricultural water supply, as well as for ecosystems.



California will almost certainly see reductions of 5 to 9 million acre-feet per year in water availability for agricultural and urban water uses in the coming decades. Most reductions are from ending groundwater overdraft, climate change, increased environmental flows, and reduced Colorado River supplies.

Without improvements in management or infrastructure, these shortages would cause direct economic losses of $1.8 to 11 billion/year, and total economic losses of $3.4 to 14.5 billion/year with up to 67,000 jobs statewide.

California has many ways to reduce these costs by combinations of expanding supplies and reducing demands across water use sectors. These responses will bring costs to water users, businesses, and residents across California. For some supply expansion or water use reduction activities, their implementation costs will exceed their shortage reduction benefits to California's people and economy.

Coordinating the responses of local, regional, and state agencies, businesses, and water users can greatly decrease statewide and local economic costs but is an immense institutional challenge. This situation would seem to call for renewed state leadership in organizing preparation for this future among California's diverse water users, management, and regulation communities.

Managing water in California is always costly and controversial. State government leadership has historically been vital for organizing and preparing for long-term water challenges. **Renewed state leadership would certainly help in organizing and implementing collective preparation for this future.**



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Technical Appendices

A - State and regional economic dependence on water

California's economy relies on water in many ways. Residents and businesses — ranging from agriculture and manufacturing to energy production— need water. Housing and commercial expansions need water. Agriculture is by far the largest water-using sector. California's economy is increasingly concentrated in cities, which has reduced, but not nearly eliminated water supply reliability needs for economic growth.

Water supplies have many end uses—from drinking water to different business needs. Each of these uses have a different value, and usually good management of water (and smart incentives) will try to maintain the most valuable water uses during shortages and leave the least valuable uses burdened with shortages (sometimes with compensation). This is why Californians try to reduce non-functional outdoor uses in cities during drought first, while keeping drinking water and the most valuable businesses unaffected.

In the following subsections, we describe how we estimated the costs of water shortages—or complementarily, the value of delivering water supplies. We focused on agricultural and urban water use, the two major sectors in the state. While other economic sectors also are important, like hydropower and recreation, these effects are more uncertain and significantly smaller.

Economic impacts of water shortages on agriculture

California's agricultural sector, including farms, ranches and plant nurseries, generated $59 billion in cash receipts in 2022. This sector also impacts other economic activities, like food processing and packaging industries, transportation services, and other businesses that provide necessary inputs such as machinery,

agrochemicals and fertilizers, or seeds. These impacts are more concentrated in rural areas and counties with more agriculturally-dependent economies. Here, severe water shortages can eliminate most of an area's economic base, unless the area can economically diversify. Poorer workers in these areas tend to be less able to migrate to other fields or areas.

Water is an essential input to all these economic processes. Less water forces farmers to decrease irrigated acreage (known as land fallowing) and can also reduce yields if crops are irrigated below their optimal water uses. This reduction in crop production will then trickle down in the supply chain by reducing the need for processing and packaging services, affecting inputs for dairies and other animal processing industries, and declining the need to transport agricultural products, among others.

To calculate the economic impact of water reductions in agriculture we use the Open Agricultural Production Model (openAg). The openAg model employs data on land use, production costs, price, yield and applied water to estimate profit-maximizing patterns of crops under varying conditions. Data for these inputs in California are available from various state and federal agencies and University of California studies such as the UC Davis Crop Cost and Return Studies, US Department of Agriculture National Agricultural Statistics Service, and the California Department of Water Resources. We calibrate our model to existing conditions (2018) and then obtain the resulting crop mix under different shortage scenarios. For this study, we divided California's agriculture in three regions: the northern part of the state (Sacramento Valley), the southern Central Valley (San Joaquin Valley), and Southern California. We obtained agricultural production estimates (including crop mix and revenues, among other variables) for different shortages. As seen in Figure A-1, the first units of water are usually used in the most productive crops following the profit-maximizing model, so agricultural production curves become flatter as water availability increases, increasing economic value at a diminishing rate. The total agricultural production estimated by our model with full water availability is about $32.7 billion in crop revenues, which represents 86% of state crop revenue production in 2018.

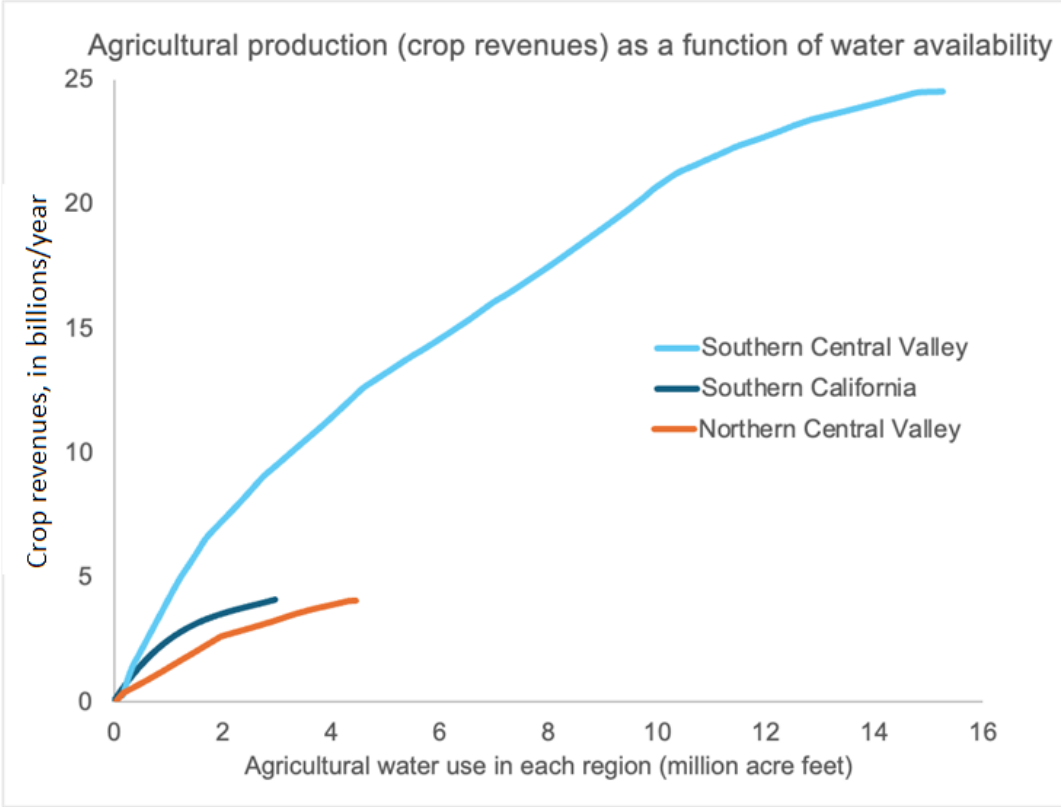


Figure A-1. Annual agricultural production as a function of water availability in California's major agricultural regions

From these production value functions, we estimate the economic costs of shortages as a reduction of production given specific reductions in water availability. An important caveat of our calculations is that we are obtaining farm revenues, which might not be the best indicator of the value of water scarcity for some reasons. Farm revenues might overestimate the economic impact because farmers also have costs, so farm benefits are less than farm revenues. However, as mentioned above, crop production also has a greater impact on the economy, because crops are an important input to other economic activities such as animal farming or food processing. Some of these broader economic impacts are estimated below. As shown in other similar studies (Escriva-Bou et al, 2023; Medellin-Azuara et al, 2019), the value of farm revenue is quite similar to the combined value added to the economy by crop production, dairy and beef production and processing industries—a value that could be considered the direct economic impact of crop production reductions in the most closely related agricultural industries.

Economic impacts of water shortage in cities

Cities provide water for human needs - including drinking water - but urban water suppliers also support the businesses that make up most of California's economic output. However, urban activities use much less water after decades of water

conservation and use efficiency programs. Also, much of the value of urban water use is concentrated in smaller industrial, commercial, and indoor household uses, so the urban economy is usually quite resilient to well-managed water shortages.

Nevertheless, citizens and urban businesses demand high reliability from water providers and are willing to pay much more than farms and most other water users for their utilities to maintain high reliability even during droughts. So urban water investment is generally much higher for cities than in the agricultural sector.

But even if the economy is generally resilient, water shortages cause significant disruptions for households and urban businesses. To calculate the economic costs of urban water shortages, we rely on standard welfare analysis. Basically, urban users obtain an implicit benefit—called consumer surplus—created by getting water at a price that is lower than the value a consumer would be willing to pay. When there is a shortage of water, an increase in the price of water might cause users to use less water, keeping the most profitable or valued uses, but reducing overall benefits—or consumer surplus. We show this effect in Figure A-2; initially users use Qo units at a Po price. When shortages reduce water availability, users reduce their use to (Qf) but preserve their most valued increments of water use, having the same effect as raising the price of water to Pf. Area A is the lost consumer surplus due to the shortage (Qo – Qf). But because water suppliers have significant fixed costs (causing the price of water to be much higher than its marginal cost), suppliers will recover their lost benefits B, that will be paid by customers. So total losses in water customers' welfare will be A + B.

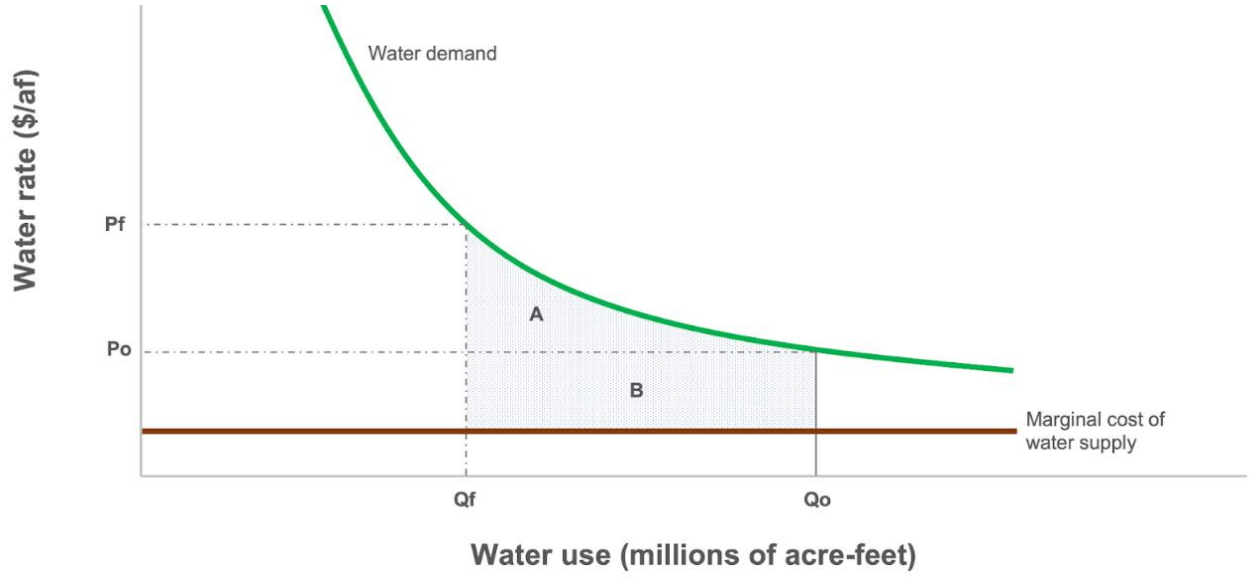


Figure A-2. Welfare analysis for a reduction in water availability.

The estimation of these effects needs data on water use, water rates, elasticities of water demand, and marginal costs of water supply. Several studies have been done

for similar estimations in California's urban sector recently (see Buck et al 2021, Mitchell et al 2016, Sunding et al 2013). In our analysis we use:

- Water use: given by our analysis of water availability and potential water shortages estimated in this study.
- Water rates: we will use average water rates for Northern California and Southern California obtained by Buck et al (2021).
- Price elasticity of demand: we will use a constant price elasticity of demand specification, assuming a value of -0.3 for the elasticity—also based on Buck et al (2021), but consistent with many other studies cited in the literature.
- Marginal cost of water supply: following Mitchell et al (2016) we use a value of $250 per acre-foot. This value is from reduced operating expenses from not supplying water.

With these data, we can estimate the shortage costs from any reduction in urban water supply, and the complementary benefits of water supplies. We capped the economic costs of shortage at $50,000 per acre-foot, assuming any shortages at this level would bring alternative supplies (like trucking water).

Therefore, we estimate the urban water value functions for the three regions, finding that the economic benefit of water supplies for cities is at least an order of magnitude more than the economic value from agriculture. The curves also have a steep slope for initial values of supply (where the most essential water demands are met) and flatten at the very end (coinciding with lowest value demands, such as non-functional outdoor use). These results are consistent with results of the other studies mentioned above.

Broader Economic Impacts

Since statehood in the mid-1800s, California has transitioned from mining and agriculture, industries with high water uses, to a much less water-intensive economy. California's gross domestic product is now dominated by services and manufacturing, which have a rather small water need from public utilities or self-supplied sources (~1%) (Dieter et al. 2018). With shortage costs of any kind, spillover effects on regional economies occur, as decreases in gross revenues, gross domestic product or consumer surplus (welfare loss), also affect sectors that sell goods and services to the affected sectors and household income. Such effects are traditionally quantified using Social Accounting Matrices methods or Input-Output models, which provide direct, indirect and induced impacts on gross revenues, GDP, income and employment. The sum of all three, direct, indirect and induced effects is often referred to as the *multiplier* or the *total effect* of an economic shock on the region's economy.

We consider recent estimates of the multiplier effects of changes in cropping patterns or gross revenue losses from farming in the San Joaquin Valley (Escriva-Bou et al.

2023), and for urban uses in California (Sunding et al, 2013, other citations). For crop agriculture and its crop-using sectors including animal products and food and beverage processing, roughly a million acre-feet in water supply shortages results in $2.7 billion in revenue losses, $1.4 billion in GDP (value added), and 15,500 jobs lost. These impacts are rather non-linear and may vary widely depending on the ability to trade water, augment supply, and the relative shortage level. Urban shortage spillover effects are more subtle. A fiscal and economic impact analysis for the extended emergency regulation for urban water conservation (Mitchell et al. 2016), estimates a fiscal cost of $673 million ($794/AF) and $1.3 billion ($1530/ AF) in consumer surplus losses. Industrial and commercial users' shortages may be costly in terms of GDP and employment. A more recent study for Orange County (Boarnet et al. 2022), estimates direct GDP losses of a 15% water shortage for businesses of roughly $115,000 per acre foot. The study also quantifies loss in consumer surplus of $5,300 per acre foot at 15% shortage. In sum, urban water shortage costs are orders of magnitude higher than irrigation shortage cost, creating some opportunities for judiciously reducing overall shortage costs by considering third party impacts.

B - Strategic Perspective

California has always had and will have more variability in water supplies. For the Colorado River, and most of southern California, reducing average water use and increasing average supplies will help maintain southern California's groundwater reserves and the Colorado River's immense reservoir water storage to dampen all but the most extreme water supply variability, from the perspective of urban users and the most profitable crops. Improving groundwater storage conditions in the southern Central Valley's immense aquifers, by reducing average use and any average augmentation in supplies will also greatly reduce economic losses from water shortages, provided infrastructure and institutions are able to store and move water to where it is needed most. In the long term, reductions in water use will be the single greatest part, but by no means the only part, of adaptation to future conditions.

The more abundant water supplies in the Sacramento Valley seem more difficult to adapt. Urban supplies, if well managed, are likely to be fairly (but not completely) reliable. The lower valued agriculture will be more vulnerable to droughts, as there will be incentives for its partial or complete fallowing to serve higher-valued demands both within and outside the Sacramento Valley. Drought shortages in Sacramento Valley plus any permanent fallowing firm up Valley water supply reliability for all sectors and allow for profitable sales of some water further south, subject to Delta conditions.

In any case, all water users should be making serious and sustained arrangements for prolonged severe droughts, involving supply management, regional and inter-regional cooperation and infrastructure, and demand management.

Perhaps the most important capability needed is for local and regional water authorities to maintain and strengthen their abilities to make decisions and investments needed for their water users. These will often require a supportive legal environment from state and federal governments.

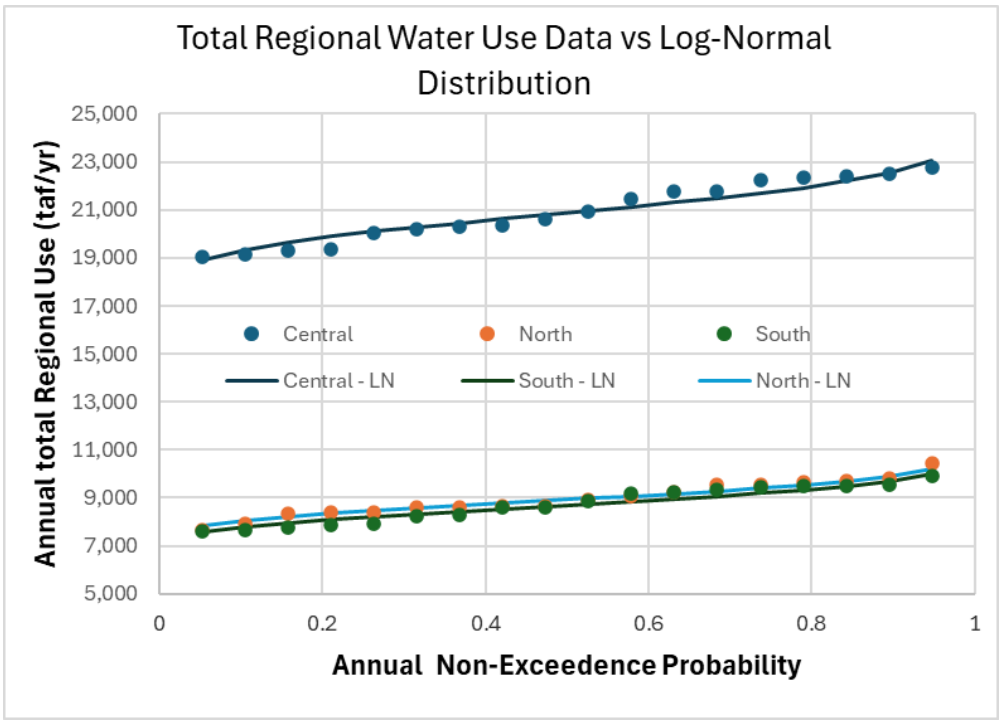
C - Recent Regional Water Availability Distributions

Statewide annual DWR water balance and use data from 2002 - 2020 (except 2017, which was unavailable) were obtained from https://data.cnra.ca.gov/dataset/water-plan-water-balance-data. These data were aggregated into three large regions with different characters:

- **North** includes Sacramento, North Coast, and North Lahontan
- **Central** includes Bay Area, San Joaquin, Tulare and Central Coast
- **South** includes South Coast, South Lahontan and Colorado

Mean and variance statistics from these data were used to fit long-normal distributions of regional total as-operated water availability, reflecting existing infrastructure and operations as well as annual runoff. The fit of these distributions for each of the three regions is shown in Figure C-1 below. Fitting these data to probability distributions allows consideration of annual water availabilities more, less, and in-between those observed in 2002-2020.

Figure C-1. Plot of fitted log-normal water availability distributions to 2002-2020 (minus 2017) DWR data



D - More detailed direct economic impact results

Table D-1 has more detailed results from the economic impact model by region and sector for the seven scenarios examined earlier.

Table D-1. More detailed economic impact model results

				Supply Losses by Region (maf/y)			Economic loss by region ($B/y)			Ave. econ loss/reduction ($/AF)		
Scenario	**Reduction (maf/yr)**	**Region**	**Proportion urban use**	**Mixed change**	**Urban only change**	**Agriculture only**	**Urban**	**Agriculture**	**Region**	**Urban**	**Agriculture**	**Region**
0. Base case (no change)	0	North of Delta	0.11	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0
		SJV + Bay Area	0.129	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0
		S. California	0.486	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0
		Total		0	0	0	0.0	0.0	0.0	0.0	0.0	0.0
1. Future likely	5	North of Delta	0.11	1.5	0	0	0.5	0.3	0.9	3,126	257	573
		SJV + Bay Area	0.129	3	0	0	1.1	1.7	2.8	2,750	649	920
		S. California	0.486	0.5	0	0	0.6	0.1	0.7	2,370	371	1,343
		Total		5	0	0	2.2	2.1	4.3			858
2. All from Agriculture - 5maf	5	North of Delta		0	0	1	0.0	0.2	0.2	0	0	0
		SJV + Bay Area		0	0	3	0.0	2.00	2.0	0	666	666
		S. California		0	0	1	0.0	0.47	0.5	0	467	467
		Total		0	0	5	0.0	2.7	2.7	0	542	542
3. Worse Future	9.5	North of Delta	0.11	2.5	0	0	1.2	0.6	1.9	4,503	287	751
		SJV + Bay Area	0.129	5.5	0	0	2.9	3.5	6.4	4,047	727	1,155
		S. California	0.486	1.5	0	0	2.4	0.3	2.7	3,225	443	1,795
		Total		9.5	0	0	6.5	4.5	10.9			1,150
4. Better worse future	9.5	North of Delta	0.11	1.5	0	1	0.5	0.68	1.2	3,126	291	478
		SJV + Bay Area	0.129	1.5	0	4	0.4	3.94	4.4	2,275	743	797
		S. California	0.486	1	0	0.5	1.3	0.5	1.8	2,735	468	1,203
		Total		4	0	5.5	2.3	5.1	7.4	0.6		777
5. All from Agriculture - 9.5maf	9.5	North of Delta		0	0	3	0.0	0.7	0.7	0	247	247
		SJV + Bay Area		0	0	4.5	0.0	4.12	4.1	0	915	915
		S. California		0	0	2	0.0	0.77	0.8	0	385	385
		Total		0	0	9.5	0.0	5.6	5.6	0	593	593
6. One MAF loss from each sector in ea. region	6	North of Delta	0.11	0	1	1	28.3	0.2	28.5	28,303	244	14,274
		SJV + Bay Area	0.129	0	1	1	6.0	0.5	6.5	5,951	546	3,249
		S. California	0.486	0	1	1	4.0	0.5	4.4	3,954	467	2,210
		Total		0	3	3	38.2	1.3	39.5	12,736	419	6,578
7. Loss to ea. sector and region, for 100TAF loss	0.6	North of Delta		0	0.1	0.1	0.26	0.02	0.3	2,595	195	139
		SJV + Bay Area		0	0.1	0.1	0.21	0.04	0.2	2,109	377	124
		S. California		0	0.1	0.1	0.22	0.03	0.3	2,205	339	127
		Total		0	0.3	0.3	0.7	0.09	0.8	2,303	304	130