RBM Handout: 06/04/24

Weekly Water Report	As of: May 28, 2024	As of: June 4, 2024	
New Hogan (NHG) TOC	**317,100**	**317,100***	**AF**
Storage:	236,960	234,844*	AF
Net Storage Change:	-1,693	-2,116	AF
Inflow:	76	19*	CFS
Release:	151	171*	CFS
New Melones (NML) Allocation	**75,000**	**75,000**	**AF**
Storage:	2,098,475	2,101,327*	AF
Net Storage change:	+8,074	+2,852	AF
Inflow:	2,830	2,967**	CFS
Release:	1,172	1,860**	CFS
Source: CDEC Daily Reports			

Goodwin Diversion (GDW)			
Inflow (Tulloch Dam):	1,363	2,570	CFS
Release to Stanislaus River (S-98):	602	966	CFS
Release to OID (JT Main):	696	837	CFS
Release to SSJID (SO Main):	296	281	CFS
Release to SEWD:	242	253	CFS
Total Release	1,836	2,337	CFS
Source: Tri-Dam Operations Daily Report			
Farmington Dam (FRM)			
Diverted to SEWD:	135	110	CFS
Diverted to CSJWCD:	180	200	CFS

Surface Water Used			
Irrigators on New Hogan:	13	33	
Irrigators on New Melones:	3	2	
Out-Of-District Irrigators:	1	3	
DJWWTP Production:	48	48	MGD
North Stockton:	10	12	MGD
South Stockton:	8	8	MGD
Cal Water:	22	24	MGD
City of Stockton DWSP Production:	13	19	MGD

District Ground Water Extraction			
74-01	0	0	GPM
74-02	0	0	GPM
North	0	0	GPM
South	0	0	GPM
Extraction Well # 1	0	0	GPM
Total Well Water Extraction	0	0	GPM
Total Ground Water Production	0	0	MGD

Note: ****The data reported here is available as of 06/02/24**
***The data reported here is available as of 06/03/24**
All other flow data reported here is preliminary, as of 9:00 a.m. on 06/04/24

RBM Handout: 06/04/24
Agenda Item: F-2b

The Magnitude of California's Water Challenges

Jay Lund, UC Davis, Josué Medellín-Azuara, UC Merced,
Alvar Escriva-Bou, UCLA

Commissioned by

CMUA
CALIFORNIA MUNICIPAL UTILITIES ASSOCIATION

Prepared by

UC DAVIS
UNIVERSITY OF CALIFORNIA

UC MERCED

UCLA

California is a region with a mostly dry climate, a high frequency of floods and droughts, a large prosperous population, dynamic globally-connected economy, and concern for diverse water-dependent ecosystems. California will always have water challenges. These challenges have changed over the last two centuries and continue to change. Due to these evolving water challenges, California has developed a range of infrastructure, technologies, and institutions that have allowed the state to prosper and grow dramatically, even as its native ecosystems struggle. California's water infrastructure, technologies, and institutions need to continue to adapt.

California will see increasing water scarcity from climate change, the end of overdrafting groundwater and the Colorado River's massive reservoirs, increased water dedications for environmental flows, and other factors, such as salination of aquifers and land subsidence reducing canal capacities. Total reduction in average water availability in the coming decades will likely range from 4.6 to 9 million acre-feet per year. For context, this is equivalent to the water use of 1 – 2.8 million acres of irrigated agriculture or most urban water use in California. Perhaps 20-30% of this loss will likely be addressed by ongoing water conservation and supply improvements, being planned and implemented, leaving a 3 – 7.2 million acre-feet/year likely net average difference between statewide water demands and availability.

Recent droughts show some growing limitations of California's water system. Droughts exacerbate how much users would be willing to pay for additional water (economic water scarcity) and water scarcity impacts far beyond average conditions. So, California needs to be concerned with changes in both average water availability and more extreme conditions. Adapting infrastructure, institutions, and preparations to manage droughts, and droughts potentially more extreme than those seen historically, along with more intense precipitation events, will be vital for maintaining public health, prosperity, and ecosystems through California's inevitable droughts.

Fortunately, California has a diverse portfolio of state, regional, and local actions for managing these challenges. Each action has costs and impacts. Most actions perform better and more sustainably when coordinated across local and regional levels, often with state involvement and infrastructure. California has many options across the state, but water decisions are rarely easy.

Some water scarcity is unavoidable for California. The economic, financial, and environmental costs of eliminating all water scarcity would certainly exceed its benefits. But tailoring portfolios of actions to changing conditions can greatly reduce costs of water scarcity within responsible economic and environmental levels and make California's overall water system more resilient to climate change. Indeed, some water scarcity (but not too much) helps water users and managers maintain attention, focus, and motivation for innovation.

Good management and policy for this situation requires organized serious attention and consistent long-term policy, without complacency or panic.

INTRODUCTION

Water supply and management is fundamental for the health, prosperity, social justice, and environmental sustainability of any society. In California, water supplies must serve a large and dynamic population, economy, and ecosystems that depend on water and water quality in a semi-arid climate with high and growing frequencies of droughts and floods. Nationally, California has many more extremely wet and dry years per average year than any other part of the country (Dettinger, 2011). This context has made water management a major practical and policy challenge for California since the 1800s (Pinter et al. 2019). Although Californians have made effective investments in water management for human purposes during this time, these investments have never occurred without prolonged discussions, analyses, and controversies. Nevertheless, important water problems remain for all sectors, with the greatest challenges for ecosystems, rural drinking water supplies, and agriculture.

Water challenges are increasing as California's climate is becoming more dominated by extremes, with higher temperatures and growing proportions of dry and wet years (Swain et al., 2018). Simultaneously, California's society and economy continue to drive both increases and decreases in water demands and overall increases in the economic value of water supplies. This report reviews the context and challenges of water management in California and how it must adapt to changes in climate, society, economy, and ecosystems. The report estimates the quantities of water likely to be lost in the coming decades from natural and human causes. The report also discusses important trends in water demands (albeit often less quantitatively). These estimates provide part of a context for public policy and investment decisions.

California is a large and diverse state, with a wide range of local and changing conditions. Water supply problems and solutions vary considerably across the state. Locally-varying integrated portfolios of supply and demand management actions have become common for most successful water supply systems in California, even as most local and regional portfolios benefit and even rely on larger regional and statewide water transfer and storage systems, particularly in preparing for and managing droughts.

For about 150 years, California's water policy focused almost exclusively on developing infrastructure and institutions to provide water for economic and population growth. During this time, California's human population and economy grew tremendously. And California's economy shifted radically from mining, to agriculture, to manufacturing, to service provision, with fundamental implications for human water demands and supplies. In each stage of economic growth, California's newer economic activities have tended to become less dependent on abundant water supplies. During this time, the development of land and water for humans has violently disrupted California's native ecosystems, eliminating about 95% of native wetlands, greatly altering the flows of rivers, and fragmenting access to riparian and wetland habitats.

Today, California's population growth has slowed overall and reversed in some places. Yet its economy continues to grow and change, and its climate is changing more rapidly.

Although economic prosperity still required water, economic growth and water supply abundance have been largely (but not entirely) decoupled at a statewide level and for most regions. Roughly 95% of California's population and economy are urban, supported by roughly 20% of California's human water use. Urban economic growth is primarily service-dominated, not driven by water abundance, and has diminishing per-capita water use rates. However, most rural areas depend economically on irrigated agriculture, where water (and labor) costs and availability often limit economic growth, even as shifts to more profitable permanent crops have increased economic returns per unit of water use.

In prosperous semi-arid regions, like California, water will usually be an economically scarce commodity (like land, labor, and excellent management) (Thompson 2011). It will rarely be economical to eliminate all water scarcity. The costs of eliminating all scarcity often exceeds the costs of accepting occasional modest amounts of scarcity. Few of us would want to pay taxes high enough to eliminate all traffic congestion or other ills. Modest amounts of scarcity also help maintain management discipline and accountability. So there is discussion on how California might improve its broad water supply and demand management portfolio to balance current and future supply costs, benefits, and impacts. The report also discusses some public policy issues for state, federal, and local governments in addressing these water supply issues.

California's Department of Water Resources (DWR) distinguishes three major water use sectors: agricultural, urban, and environmental. Agricultural water use is predominantly water applied to irrigated lands from both surface and groundwater sources. Nearly all crop agriculture in California is irrigated. Rainfed lands produce some winter crops and forage for cattle, mostly producing much less economic value. Urban water use includes usage in cities and rural areas for residential, commercial, industrial, and institutional purposes. Environmental uses, according to DWR, includes water for instream flow requirements, managed wetlands, required Delta outflow, and wild and scenic river flows.

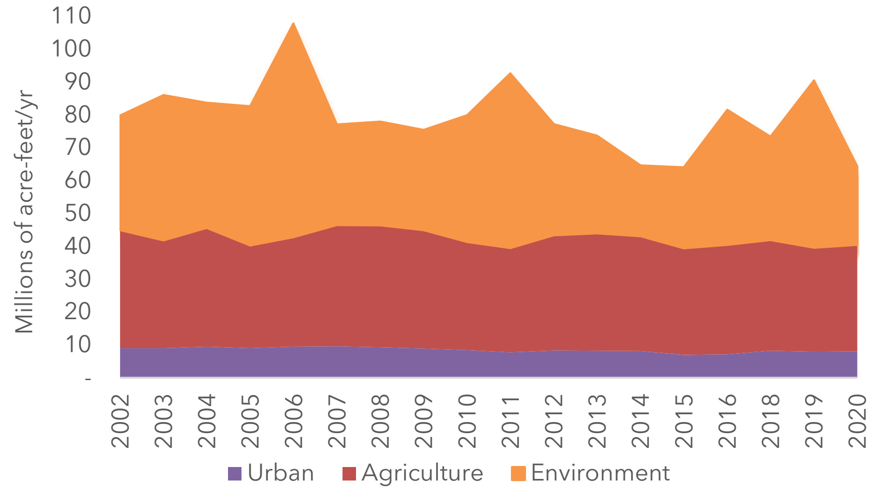
Current Water Use in California

From all accessible 2002-2020 data, average annual applied water use in California is roughly 80 MAF (million acre-ft)/yr, 47 percent is classified as environmental, 43 percent for irrigated agriculture and nearly 11 percent for cities and communities (Figure 1).[1] In most individual years and especially in dry years, agriculture uses the highest proportion of water among the three sectors. But in wet years environmental uses have the largest share of water use (Figure 2). This accounting for *applied water* (raw water use), which does not account for return flows to streams, reuse and recycling and groundwater recharge. *Net water use* (or consumptive use) is applied water use minus return flows available for subsequent use. Net water use is more complex to estimate due to a myriad of factors including current and antecedent soil and atmospheric conditions driving evapotranspiration, land cover, irrigation technology (in the case of agriculture) and the ability of the soil and the streams to recapture runoff and deep percolation. The portion of water returning to the system lowers net water use.

Of all major uses, environment water use shows the most fluctuations with an average of 37 MAF/yr, depending heavily on wet years. Agriculture follows in applied water use fluctuations, averaging 34 MAF/yr, and a slightly declining trend. Urban water uses are rather stable, with a slight decline in trend despite population growth. Water use fractions also vary greatly across California, with environmental use being predominant on the North Coast and being mostly absent in the Tulare, Central Coast, and Colorado River basins (Table 1).

[1] Rounding prevents these percentages from adding to 100%. The actual percentages are 46.6% for the environment, 42.8% for agriculture, and 10.7% for urban water use.

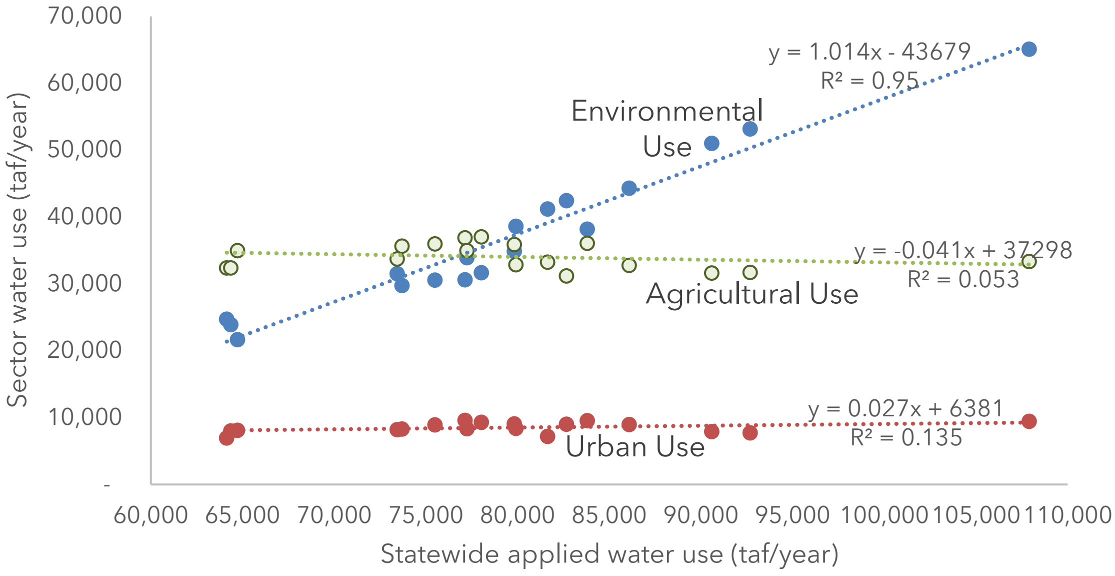
FIGURE 1: TOTAL STATEWIDE APPLIED WATER USE BY SECTOR 2002-2020



Notes: Data from the Department of Water Resources. Data for 2017 is unavailable.

Figure 2 shows how each sector's water use has varied in recent years with the overall wetness of each water year. Although the environmental sector has the greatest average water use (relying on wetter years for most of its use), agriculture is the largest sector in most years (increasing use in dry years). Urban water use decreases slightly in drier years, and is rather steady.

FIGURE 2: SECTOR WATER USE VS. TOTAL APPLIED USE (TAF/YEAR)



Notes: Data from the Department of Water Resources, 2012-2020. Data for 2017 is unavailable.

Table 1 shows 2002-2020 average applied water use by sector for nine regions and the statewide summary by sector. Water use by sector and region varies widely in California (both across and within these regions) but has remained relatively stable in terms of proportions of use by sector, except for the coastal areas south of the state where highly urbanized areas increase opportunity costs of water use in agriculture.

TABLE 1: AVERAGE APPLIED WATER BY SECTOR AND REGION (MAF/YEAR, 2002-2020)

Region	Agriculture	Urban	Environmental	All sectors
Central Coast	1.08 (74%)	0.28 (19%)	0.09 (6%)	1.45
Colorado River	3.99 (88%)	0.53 (12%)	0.04 (1%)	4.56
North & South Lahontan	0.79 (53%)	0.29 (19%)	0.41 (28%)	1.50
North Coast	0.83 (4%)	0.15 (1%)	18.22 (95%)	19.20
Sacramento River	8.25 (36%)	0.84 (4%)	13.68 (60%)	22.77
San Francisco Bay	0.16 (11%)	1.21 (86%)	0.05 (3%)	1.42
San Joaquin River	7.37 (67%)	0.63 (6%)	3.03 (27%)	11.03
South Coast	0.73 (15%)	3.94 (82%)	0.11 (2%)	4.79
Tulare Lake	10.84 (84%)	0.65 (5%)	1.44 (11%)	12.93
Statewide	**34.05** (43%)	**8.51** (11%)	**37.08** (47%)	**79.63**

Notes: *Data from the Department of Water Resources. Data for 2017 is unavailable.*

Some of the main characteristics of these sectoral uses are:

Agricultural water use. California's more than irrigated 300 crop commodities, produce more than $50 billion/year of revenues, and use roughly 80 percent of human water use (agriculture plus urban), mostly for over 5 million irrigated acres in the Central Valley. Other major irrigated areas are in the southern inland corner of the state supplied by the Colorado River. Coastal agriculture employs smaller amounts of surface water supplies and groundwater, with high revenue per unit of water applied. Agriculture in the northeast is mostly forage crops, supplied mostly by groundwater in Siskiyou and Modoc counties and a mix of local surface water and groundwater in Shasta and Lassen counties.

Urban and domestic water use. With nearly 40 million people living in California, the 8.5 MAF/yr total annual average water use in cities and rural communities have remained relatively stable over the past two decades despite population nearly doubling. Aggressive water conservation programs in most cities that include outreach, retrofitting of appliances, and improvements in outdoor landscape water use have caused sizable declines in per capita water use. The South Coast concentrates nearly 60 percent of the state's population and uses 3.9 MAF/yr of water mostly from surface water imported from California's wetter northern regions, the Colorado River, and Owens Valley. Limited supplies from local streams, coastal aquifers and recycling also support urban water uses in southern California. The San Francisco Bay Area, follow the south coast in urban water use with 1.2 MAF/yr. Scattered cities along the Central Valley including Chico, the Sacramento metropolitan area, Stockton, Modesto, Turlock, Merced, Fresno, Visalia and Bakersfield use about 2.1 MAF/yr altogether. The urban water footprint of the eastern part of the state (Lahontan) and the North Coast is small, averaging 432 TAF/yr for the 2002 to 2020 historical period.

Small rural systems' water use is relatively small and hard to compile in the statistical records. The State Water Resources Control Board is modernizing the small water systems and domestic well water quality data and the state is also providing funding to address water quantity and quality issues in these communities (see Box 1).

BOX 1. Water Problems of Rural and Small Communities

Rural households and small communities have among the state's most challenging water supply problems. These include some tribal communities.

Roughly 1.3 million Californians are served by domestic wells, and approximately 250,000 more are supplied by small water systems with less than 200 connections. Users of such small systems are the most vulnerable in California, facing water quality, affordability, and water shortage problems. More than 250 water systems serving 900,000 people were out of compliance with drinking water standards in 2020, and over 150,000 use domestic wells in areas with groundwater pollution exceeding maximum levels for 1 or more contaminants (Pace et al., 2022). Furthermore, almost 6,000 domestic wells have dried during the past 10 years from declining groundwater levels. These problems disproportionately burden poor communities of color especially in the San Joaquin Valley, but also in other regions (Pauloo et al., 2020).

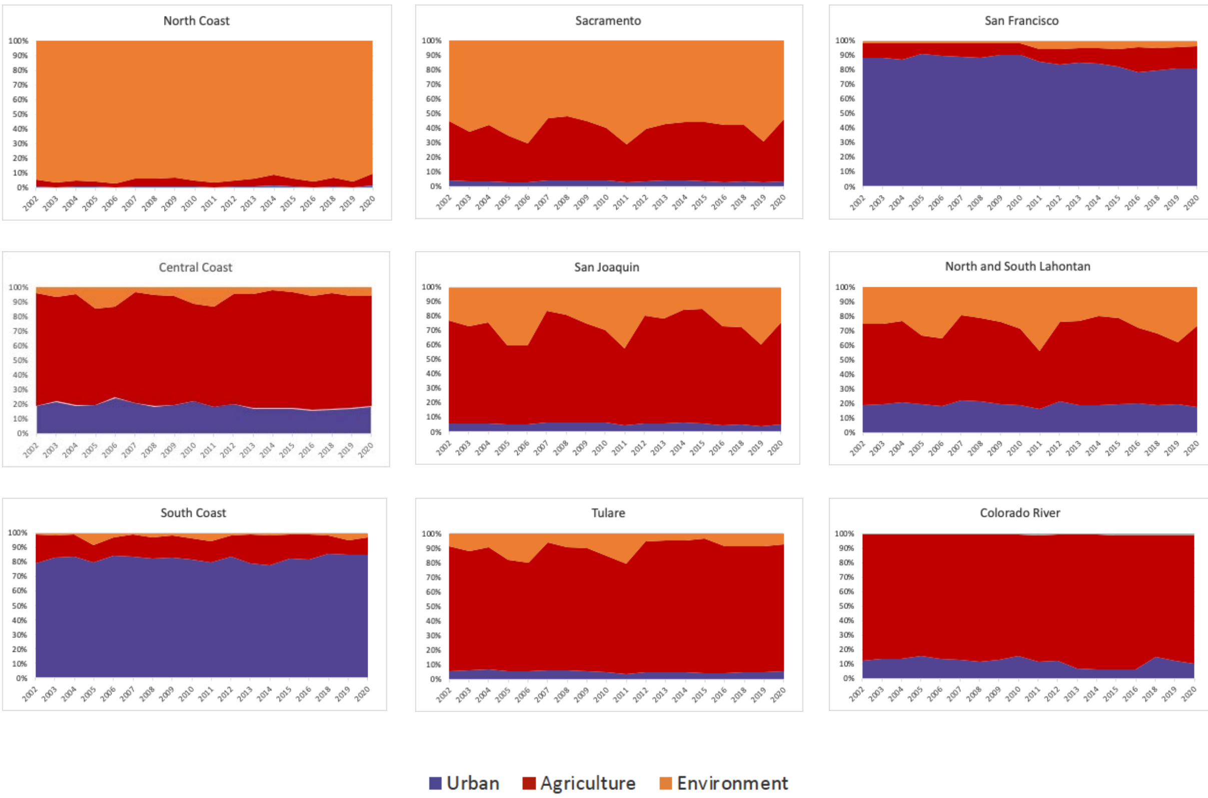
The water use of these communities is relatively small—around 260,000 acre-feet per year (assuming 150 gallons per capita per day), about 0.6% of all water used for cities and farms. Their reliance on groundwater exposes them to quality and groundwater decline issues, and their lack of institutional capacity and small scale increases their economic and health vulnerability.

The state is trying to address some of these problems through the Safe and Affordable Funding for Equity and Resilience (SAFER) program, which provides $130 million annually over 10 years. Consolidation of smaller systems into larger ones is reducing vulnerabilities for some, although challenges such as local disagreements and physical distance hamper consolidation (Chappelle et al., 2021). For dry wells, the state was faster to respond during the 2020-22 drought than previous droughts, but mitigating and addressing well vulnerability under the Sustainable Groundwater Management Act often remains unresolved.

Environmental Use. Water use in wetlands, wild and scenic rivers, streamflow requirements, and ocean outflow are included in DWR's environmental use. In dry years statewide, most water is used by agriculture. Yet all environmental uses increase from additional water in wet years. On average roughly 37 MAF/yr are used statewide for environmental purposes, but with great yearly fluctuations (Figure 2). Regions with the highest proportion of water in environmental uses are the North Coast and the Sacramento Region, followed by North and South Lahontan and the San Joaquin River basin.

Differences in sectoral water uses are quite significant across California regions. Figure 3 shows the San Francisco Bay and South Coast regions have the highest shares of urban water use, whereas water use in San Joaquin Valley, Tulare, Central Coast, and Colorado River regions is predominantly agricultural.

FIGURE 3: HISTORICAL SHARE OF APPLIED WATER USE BY SECTOR FOR CALIFORNIA'S HYDROLOGIC REGIONS



Notes: Data from the Department of Water Resources. Data for 2017 is unavailable.

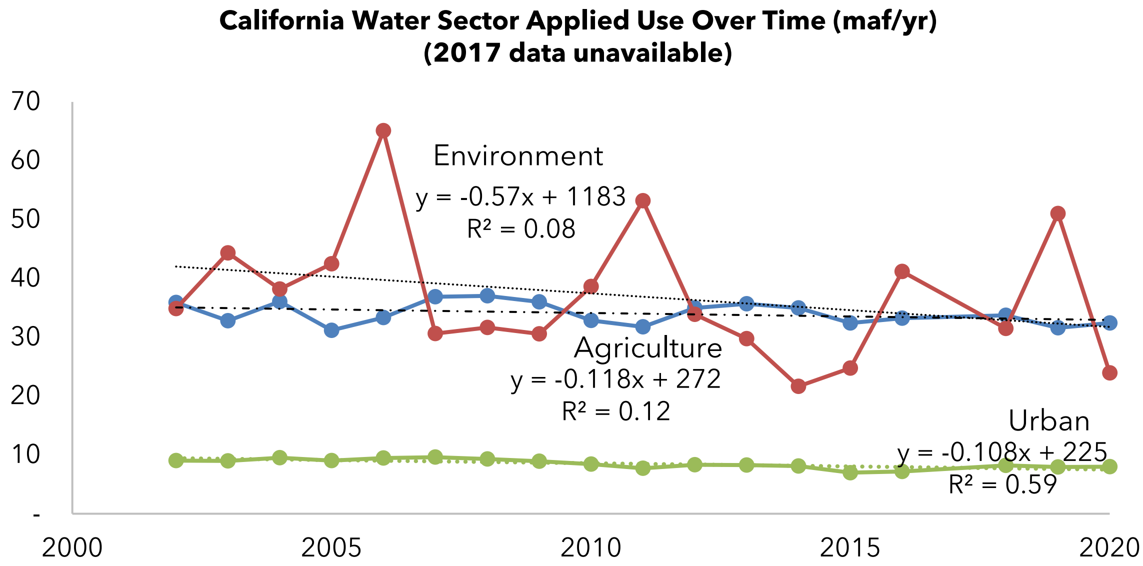
Trends and Future Water Demands

Water uses change significantly over time, reflecting changes in economic structure, technologies, and society's preferences and priorities. The structure of California's water uses, law, infrastructure, and regulations have changed historically, from serving a mining economy, to an agricultural economy, to a wealthier predominantly urban economy with a substantial agricultural component and concerns for both environmental and economic health.

Water uses continue to change. Newer indoor plumbing technology and codes and conservation programs are reducing per-capita urban water use. Market and technological shifts are reducing many industrial water uses. Market and technological shifts to more profitable and permanent tree and vine crops have changed seasonal crop water demands and increased costs for crop fallowing. Environmental regulations have increased dedicated environmental water uses in some rivers.

Statewide urban water use totals are slowly but steadily declining (Figure 4). Total agricultural water use reductions has occurred slightly faster (in acre-ft/year) and slower (as a percent reduction per year) than in the urban sector. This is likely from a mix of more frequent droughts in recent decades, urban expansion displacing some agriculture, some land retirement from soil salination, and other factors. Total environmental water use, by this accounting, is much more erratic and variable, but has declined at the greatest long-term rate, probably due to more recent major drought years.

FIGURE 4: RECENT CHANGES AND TRENDS IN ANNUAL APPLIED WATER USE BY SECTOR



Projecting water demands in California involves challenges and uncertainties in future climate, land use trends, regulation, public choices, and water use preferences and costs. The remainder of this section summarizes potential changes in water use for each sector.

Urban demands. Urban demands are mostly driven by population and per capita water use. The latest population estimates and projections of the California Department of Finance show California's population peaked by 2020, but the population seems likely to grow slowly again. By 2040 population, would be 40.1 million, from 39.5 million in 2020. However, projections show some regions like the San Joaquin Valley might grow by 8% from 2020 to 2040. With current per capita urban use and population projections, total urban water use is unlikely to grow at the pace of last century. Improvements in water use efficiency and conservation policies will likely drive further reductions in total urban water use perhaps by a further 10-20%, depending on population growth.[2]

Agricultural demands. Agricultural water use depends largely on applied water requirements for crops and irrigated land area. California's crop production will be

[2] California urban use decreased from over 9 million acre-feet in early 2000s, to around 8 maf for 2018-20 period. This 13% water use reduction occurred even as population increased from less than 35 million to 39.5 million.

limited by the costs and availability of both water and labor, but seems less likely to be limited by global market prices. With potential water limitations from groundwater regulation, soil and water salination, or increased environmental flows (discussed below), changes in total agriculture water use will depend on cropping patterns and evapotranspiration demands.

California's cropping patterns continue to shift towards permanent crops, about a third of irrigated land area today, which harden interannual irrigation demands yet increase the economic value of water use in irrigation. Strong local and global demands for these high value commodities will drive crop decisions and the interplay with annual crops, primarily vegetables and non-tree fruits. Nevertheless, production of forage crops (*e.g.* alfalfa, corn, and irrigated pasture), may remain under strong livestock and dairy commodity prices driven by national policy.

Changes in crop evapotranspiration from a changing climate will affect agricultural water demands. Some estimates indicate that higher temperatures and dry soil and atmospheric conditions may increase evaporative demands by 5 to 10% in dry years (Moyers et al. 2024). Such increased irrigation demands may increase gaps between supply and demand and increase overall scarcity. Whereas fluctuations in precipitation might not give a conclusive projection on water potentially available for irrigation, higher temperatures alone may significantly narrow agricultural water availability during droughts. Given California's climate and soils and global market preferences for its crops, water and labor costs and availability are the most likely limits on agricultural water use.

Environmental demands. Regulations are likely to continue and accelerate to improve or maintain ecosystem health with a changing climate. These will include water quantity regulations as well as standards for water quality and salinity control, especially in the Central Valley and the Colorado River (Szeptycki et al., 2018). Ecosystem water demands are especially challenging to forecast as these ecosystems change in species composition and spatial extent with climate change and non-native species, and policymakers face existential evaluations of the feasibility, resources, and sustainability of alternative ecosystem objectives and management. Sustaining native and desirable ecosystems for California will likely require more water and other resources, implying that other sectors and potentially new sources will be required to supply these resources.

California's ecosystems are in a non-stationary period where more native species are becoming dependent on management. In many areas, most aquatic species are non-natives, with more likely in the future. Higher temperatures, longer summers, more evapotranspiration, and less snowpack are making California less suitable for many of its native species. Some major native fish species (salmon and Delta smelt) now depend on hatcheries. Waterfowl and their habitats often depend on management. There are changes in recreational and commercial demands for ecosystems, and perhaps changes in demands for existence values for various ecosystems.

These changes have likely profound implications for water management and what we want practically from ecosystems, and will bring challenges for infrastructure and operations that serve agricultural and urban water uses. Long-term policy discussions and science are needed to support adaptation for these changes. It seems clear that there is substantial societal pressure and demands to substantially expand water availability for ecosystems, no matter how these uncertainties develop. This is reflected in the next section's discussion.

California's long-term water supplies are constantly changing as water demands evolve from a variety of residential, agricultural, and industrial uses, new technologies for supplies and demands, changing costs of alternatives, changing social values and conditions for ecosystems, and now a changing climate. In the following sub-sections, we compile the main changes expected in the next 20-30 years using information from several sources.

Anticipated Water Supply Losses

California's water supplies are undergoing a variety of changes. Table 2 presents a non-exhaustive list of ongoing and anticipated major changes in water supplies in the coming decades. Although losses to conventional water supplies cannot be estimated with accuracy, such losses will be sizable and likely to range between 4.6 and 9 million acre-ft per year on average. This is equivalent to the consumptive water use of 1.5 - 3 million acres of irrigated crops in California or 50% - 90% of statewide urban water use.

TABLE 2: ANTICIPATED MAJOR CHANGES IN WATER SUPPLIES FOR CALIFORNIA IN THE COMING DECADES (See Appendix for sources)

Change	Estimated Average Loss Quantity	Description
Ending groundwater overdraft	2-3 maf/year	SGMA requires eliminating groundwater overdraft by 2040
Reduced Colorado River supplies	0.5-0.8 maf/year	Address historical imbalance of about 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.		

Ending groundwater overdraft under California's 2014 Sustainable Groundwater Management Act (SGMA) will eliminate 2-3 million of acre-feet/year of unsustainable groundwater pumping in California. Most of these reductions are needed in the San Joaquin Valley (Escriva-Bou et al., 2023), but other regions, like the Central Coast and Sacramento Valley (Cole et al., 2023) also will need to reduce pumping (or bring new supplies) to end groundwater overdraft. The exact amount of overdraft in California is unknown, and could exceed this estimate.

Reduced Colorado River supply to California is needed to stabilize reservoirs and improve sustainability of overall Colorado River basin water supplies. Basin-wide reductions in water use of 1.5-2.5 maf/year will be needed to balance basin supplies and uses (Schmidt et al., 2023), with climate change requiring higher reductions. If the traditional "Law of the River" holds strictly, California's large senior Colorado River supplies might be largely unaffected, forcing other states to accommodate greater reductions in basin water use. This is plausible but seems unlikely. California's large share of agricultural water use from Lower Colorado River supplies will likely mean that California ultimately absorbs a greater (perhaps the greatest) share of lower Colorado Basin water use reductions, likely with monetary compensation to agricultural water users.

Climate change will increase evaporation and evapotranspiration (ET) from watersheds and crops, reduce snowpack, raise sea levels affecting Delta exports, and cause more intense atmospheric rivers and other changes. Some climate impacts are already evident. The overall net loss to California's water supplies from climate change seem likely to average between 1-3 maf/year, even with some reoperation of water systems, and will worsen California's already high seasonal and interannual variability in surface water supplies, challenging both flood and drought management. The effectiveness of water management adaptations will greatly affect the magnitude and form of climate change impacts.

Increased environmental flows for Bay-Delta outflows and other streams seem inevitable to comply with environmental laws, regulations (State Water Resources Control Board, 2018, 2023), and society's overall preferences. These seem likely to total 1-2 maf/year. Environmental requirements might further increase with climate change.

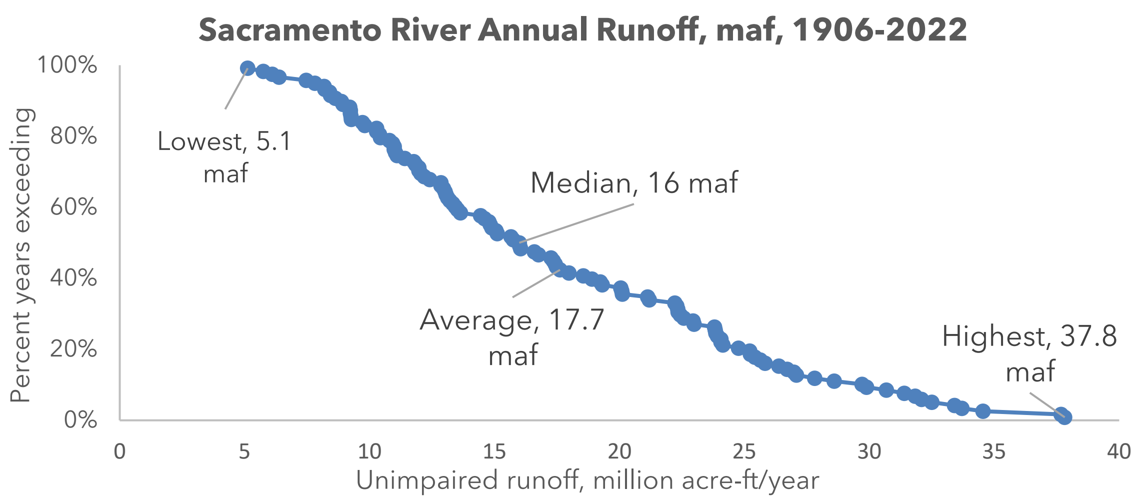
Other supply losses are also likely. In the coming decades, salination of some aquifers will render them less useful, particularly in closed basins such as the Tulare basin. Some aquifer salination is already occurring in parts of the southern Central Valley, reducing drought storage of fresh water in some aquifers. Impairment of water supplies from nitrate or other pollutants also may reduce availability of safe drinking water where treatment costs are prohibitive. Lastly, land subsidence from groundwater pumping—which has reduced canal conveyance capacities in the southern Central Valley—might also reduce the ability to capture water from wetter years for this region. Because most land subsidence is from compaction in aquifer clay layers (which cannot be recharged after compaction), this should not greatly affect overall aquifer recharge storage capacity. These losses are clear qualitatively, but have been only partially quantified.

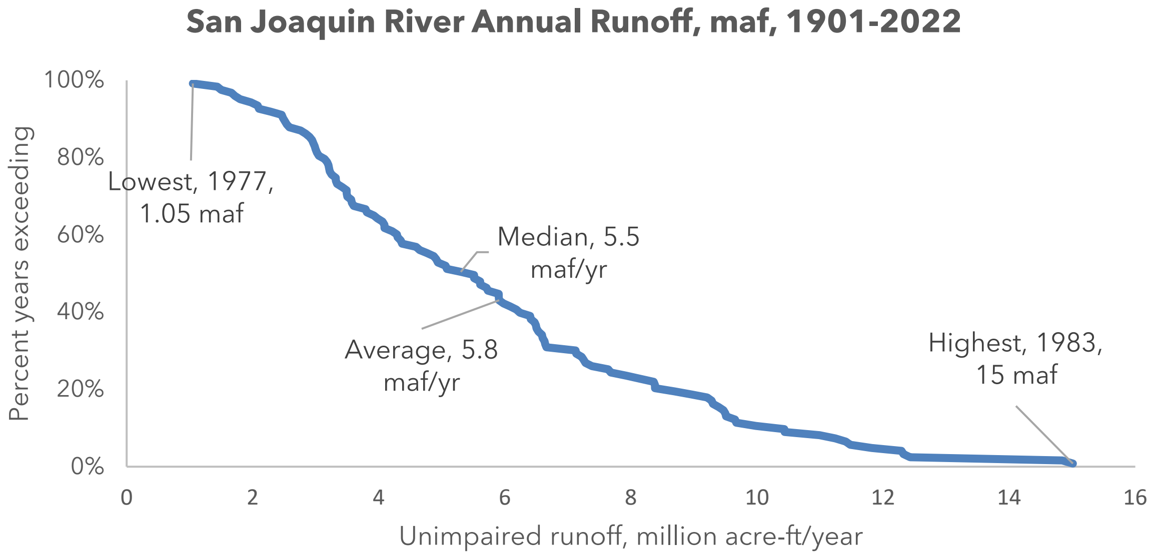
Droughts and Variability in Supplies

Because many water supplies vary widely between wet and dry years, average water scarcity is only a rough and lagging indicator of water shortage problems. Water shortages are most severe and felt most acutely in droughts. Figure 5 shows the historical variability in runoff from California's largest river (Sacramento River) from 1906-2022, where the lowest year produced less than 30% of the average year and the wettest year produced more than twice the average runoff. Smaller streams usually have even greater variability. Maximum San Joaquin River annual flow is almost 15 times greater than its lowest annual flow.

Given the potential economic costs of large shortages during drought, urban water providers must prepare for deep and prolonged droughts and other forms of water shortage, even if they feel supplies are adequate for average conditions and small droughts. The same is true for agricultural water users, particularly as shifts to permanent crops increase potential costs of fallowing large crop areas during drought. Environmentally, many years of dry conditions can exacerbate depletions of fish stocks. Droughts lasting more than three years can deeply deplete all cohorts of salmon runs, which exceed their typical three-year life span and bring other environmental damages.

Figure 5: Historical Variability in Sacramento River and San Joaquin River Annual Runoff





Notes: Data from CDEC (http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST)

If well managed, small shortages typically have a manageable cost, where water systems and users are well prepared. But prolonged large shortages can bring much larger economic and environmental costs. Extreme shortage events are of the greatest interest and pose the greatest threats, but preparation for extreme events can have significant costs.

California's intertied water system has unusual capacity to move and store water across much of the state to more flexibly respond to such situations, and greatly lower its costs. However, this physical capacity is not without limits. There also are concerns from many local and regional managers and users that both infrastructure and institutional capacity are inadequate to prepare for and take advantage of this potential capacity, particularly with growing regulations and competition for water during droughts. This context implies that during extreme drought, shortages could become much larger than the averages presented above. The box below summarizes the 2015 drought in California, as an example of drought management and a reminder of the importance of preparing and investing for extreme conditions before droughts. Most investments must occur before droughts and floods.

BOX 2. Multi-sector Impacts of the 2015 Drought on in California

During 2015, the deepest year in the 2012-2016 California drought, the cumulative effects of already dry conditions affected various sectors differently, such as agriculture, rural and urban communities, hydropower, forests, recreation and aquatic ecosystems (Lund et al. 2018). Sectors with more information facilitate quantification of drought impacts.

For example, agriculture saw 550,000 more acres idled land than in non-dry years with direct costs of $1.8 billion (Lund et al. 2018). Remote sensing data, land use surveys and hydro-economic models (Medellín-Azuara et al. 2015) allow setting baseline and drought conditions to quantify impacts. Hydropower generation declined during 2012-2016 by $1.9 billion (Kern et al., 2020). Although, wildfire damage costs exist and revenue losses for recreation can be estimated, parsing out the effects from drought can be daunting.

Shortage costs for cities and rural water supply systems are less overt. Unlike straightforward calculations of profit loss, recreation revenue loss, and wildfire damage, the economic valuation of water scarcity involves more complex understanding of welfare losses, which hinge on the collective consumer preferences for water use.

Urban utilities' losses in water sales from drought conservation, can be a proxy for drought impacts, although neglecting additional consumer losses. Large urban utilities were required to reduce water use 25% overall in 2015, due to a statewide mandate. Some areas of southern California and elsewhere required greater use reductions. Some isolated and coastal cities had more urgent shortages.

Small rural water systems, which supply drinking water and sanitation, were often vulnerable to drought impacts on groundwater elevation and quality, but lacked the funding and organizational capacity. Nitrate contamination (Harter et al. 2012), and additional agricultural pumping during drought affect rural communities due to their small scale (with higher costs) and lack of organization and funding. At least 1,264 wells went dry in 2015 statewide, with replacement costs often in the tens of millions of dollars range.

The population of more rural systems is more vulnerable to shortage of water in quantity and quality during drought. Some efforts since the 2012-2016 have improved prospects for identifying hotspots for rural water shortage and aid in planning emergency water supply, but further overhaul of these systems is perhaps decades ahead. Funding for safe drinking water in rural communities remains modest compared to overall state water costs.

Lastly, keeping ecosystem functions in rivers and the Delta required non-trivial reductions in upstream diversions and Delta exports. During 2015 roughly 1.1 MAF were made available to maintain Delta outflows to support both ecosystem functions and manage seawater intrusion. With water worth many hundreds of dollars an acre-foot in the market during droughts, devoting such large amount of water quickly raises costs from the millions to the next orders of magnitude, plus additional less quantified losses from native species risks from flow and habitat conditions.

Overall, the year 2015 of the 2012-2016 drought showed that sectors which were the most prepared (cities) suffered much fewer losses than sectors which use much more water, but were much less prepared (ecosystems, rural water users, and agriculture). It also demonstrates how much water investments firm supplied in drought years for well-invested water use sectors.

New infrastructure can provide some additional water supplies and some additional efficiencies in existing water uses, but is unlikely to supply enough to eliminate all water scarcity in most years. As often the largest human use, agriculture in California (and other Colorado basin states) is likely to lose water to other sectors either through compensation (e.g., water market purchases) and/or regulatory reallocation to environmental purposes. The economic impact of such reallocations is in the billions of dollars. Incentives for permanent and temporary fallowing programs like in the Sacramento-San Joaquin Delta and the Colorado River may become more common.

1. California's health, wealth, and sustainability have always been challenged by its climate and water availability. These challenges have evolved historically, and will continue to change and demand attention. California's water infrastructure, technologies, and institutions need to continue to adapt.

2. California water supply availability is becoming constrained by the transition to groundwater sustainability, impacts of climate change, and needs to increase environmental flows for ecosystem health, and other factors. We estimate that the magnitude of this decline could average between 4.6 to 9 million acre-feet per year—approximately 10 - 20% of current statewide water use for cities and farms. Drought shortages can be much larger and more damaging than average shortages, as seen in recent decades.

3. Some water supply losses will be reduced by ongoing local and regional actions to augment supplies and reduce demands. Ongoing efforts to increase water supply by capturing additional flows and reducing urban use might reduce these losses by 20-30%. A sizable average year gap will remain to be addressed through a combination of further supply expansions and water use reductions.

4. Recent droughts show some of the growing limitations of California's water system. Droughts exacerbate water scarcity and its impacts far beyond average scarcity conditions. So, California needs to be concerned with more than average changes in water availability. Adapting infrastructure, institutions, and preparations to manage droughts, and droughts potentially more extreme than those seen historically, will be vital for maintaining public health, prosperity, and ecosystems through California's inevitable droughts.

5. Fortunately, California has a diverse portfolio of actions available at the state, regional, and local levels for managing these challenges. Each of these actions has costs and impacts. These actions perform better and more sustainably when coordinated across local and regional levels. California has many options across the state, but water decisions are rarely easy.

6. Some water scarcity is unavoidable for California. The economic, financial, and environmental costs of eliminating all water scarcity would certainly exceed its benefits. Tailoring portfolios of actions can greatly reduce water scarcity costs to economically and environmentally responsible levels.

7. With prudent and deliberate actions, most, but not all, water uses can be reliably supported, while keeping a thriving economy. Good management and policy for this situation requires organized serious attention, without complacency or panic.

Alam, S. et al. "Can Managed Aquifer Recharge Mitigate the Groundwater Overdraft in California's Central Valley?" *Water Resources Research* 56, no. 8 (2020): e2020WR027244.

Ayres et al. (2023) Water Use in California's Communities. Fact Sheet. Public Policy Institute of California. Available at <https://www.ppic.org/publication/water-use-in-californias-communities/> January 3, 2023.

Barton H. Thompson Jr., Water as a Public Commodity, 95 *Marq. L. Rev*. 17 (2011). Available at: https://scholarship.law.marquette.edu/mulr/vol95/iss1/California Natural Resources Agency (2022). California's Water Supply Strategy. Adapting to a hotter, drier future. Available at < https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Water-Resilience/CA-Water-Supply-Strategy.pdf>

Cole, S., Greenspan, K., & Ayres, A. (2023, November). Measuring Groundwater Overdraft in the Sacramento Valley. Retrieved January 14, 2024, from https://www.ppic.org/blog/measuring-groundwater-overdraft-in-the-sacramento-valley/

Delta Independent Science Board. *Review of Water Supply Reliability Estimation Related to the Sacramento-San Joaquin Delta*. Report to the Delta Stewardship Council. Sacramento, California, 193 pp., June 2022.

Department of Water Resources (2018). Water available for replenishment. Final Report. Available at < https://h8b186.p3cdn2.secureserver.net/wp-content/uploads/2020/02/Water-Available-for-Replenishment-Final-Report.pdf> or https://cawaterlibrary.net/document/water-available-for-replenishment-2018/

Dettinger, M. (2011). Climate Change, Atmospheric Rivers, and Floods in California – A Multimodel Analysis of Storm Frequency and Magnitude Changes1. *JAWRA Journal of the American Water Resources Association*, *47*(3), 514–523. https://doi.org/10.1111/j.1752-1688.2011.00546.x

Escriva-Bou, A. (2019). Appendix D: Optimizing Supply and Demand Management Actions to Bring Groundwater Basins into Balance. Water and the future of the San Joaquin Valley. *Public Policy Institute of California*, *100*.

Escriva-Bou, A., Hanak, E., Cole, S., & Medellín-Azuara, J. (2023). *The Future of Agriculture in the San Joaquin Valley*. Public Policy Institute of California. Retrieved from https://www.ppic.org/publication/policy-brief-the-future-of-agriculture-in-the-san-joaquin-valley/

Harter, T., 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. 78 p., 2012.

Lund, J. (2022), "Follow the Water!," CaliforniaWaterBlog.com, July 24, 2022

Lund, J.R., J. Medellín-Azuara, J. Durand, and K. Stone, "Lessons from California's 2012-2016 Drought," *J. of Water Resources Planning and Management*, Vol 144, No. 10, October 2018

Lund, J. and J. Medellín-Azuara (2023), "Resistance is Futile – Agriculture is Key to Fixing Lower Colorado River Water Shortages," CaliforniaWaterBlog.com, February 5, 2023

Moyers, K., Abatzoglou, J. T., Escriva-Bou, A., Medellín-Azuara, J., & Viers, J. H. (2024). An invisible water surcharge: Climate warming increases crop water demand in the San Joaquin Valley's groundwater-dependent irrigated agriculture. *PLOS Water*, 3(3), e0000184. https://doi.org/10.1371/journal.pwat.0000184

Pauloo, R. A., Escriva-Bou, A., Dahlke, H., Fencl, A., Guillon, H., & Fogg, G. E. (2020). Domestic well vulnerability to drought duration and unsustainable groundwater management in California's Central Valley. Environmental Research Letters, 15(4), 044010. https://doi.org/10.1088/1748-9326/ab6f10

Pinter, N., J. Lund, and P. Moyle. "The California Water Model: Resilience through Failure," Hydrological Processes, Vol. 22, Iss. 12, pp. 1775-1779, 2019.

Schmidt, J. C., Yackulic, C. B., & Kuhn, E. (2023). The Colorado River water crisis: Its origin and the future. WIREs Water, 10(6), e1672. https://doi.org/10.1002/wat2.1672

State Water Resources Control Board. (2018). Substitute environmental document in support of potential changes to the water quality control plan for the San Francisco Bay-Sacramento-San Joaquin Delta Estuary: San Joaquin River flows and Southern Delta water quality. Retrieved:https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/2018_sed/docs/00_ES.pdf

State Water Resources Control Board. (2023). Staff Report/Substitute Environmental Document in Support of Potential Updates to the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary for the Sacramento River and its Tributaries, Delta Eastside Tributaries, and Delta. SWRCB. Retrieved from https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/staff_report.html

Szeptycki, L., Pilz, D., O'Connor, R., and Gordon, B. 2018. Environmental Water Transactions in the Colorado River Basin: A Closer Look. Stanford Woods Institute for the Environment: https://purl.stanford.edu/tx230zb7767.

Swain, D. L., Langenbrunner, B., Neelin, J. D., & Hall, A. (2018). Increasing precipitation volatility in twenty-first-century California. Nature Climate Change, 8(5), 427–433. https://doi.org/10.1038/s41558-018-0140-y

Subcategory	Sources and assumptions
Groundwater cuts to achieve sustainability	From Escriva-Bou et al. (2023) for the San Joaquin Valley, from Cole et al. (2023) for the Sacramento Valley, and assumed 10% of current groundwater use in the Central Coast and South Coast.
Colorado River	Following Schmidt et al (2023), we assumed a 27% contribution from California. Then, we assume that most of the impact will be in the Colorado hydrologic region, and a minor proportion in the South Coast.
Climate change	From Escriva-Bou et al. (2023) for the San Joaquin Valley and assumed a 1% increase in agricultural and outdoor urban demands for the other regions. Moyers et al 2024 show about 5% additional crop use with climate warming. Additional losses from watershed before runoff and aquifer recharge.
Environmental regulations	Following SWRCB (2023), using the 55 unimpaired flow scenario.