California WATER COMMISSION

Annotated Bibliography of Drought Resources

Academic Journal Articles

Albano, C. M., Abatzgolou, J. T., McEvoy, D. J., Huntington, J. L., Morton, C. G., Dettinger, M. D., & Ott, T. J. (2022). A multidataset assessment of climatic drivers and uncertainties of recent trends in evaporative demand across the continental United States. *Journal of Hydrometeorology, 23*(4), 505-519. https://doi.org/10.1175/JHM-D-21-0163.1

The authors assess recent trends in evapotranspiration and its drivers in the United States, finding that increased atmospheric thirst has already become a persistent forcing of western landscapes and water supplies toward drought and will be an essential consideration for land and water management planning going forward.

Banerjee, O., Bark, R., Connor, J., & Crossman, N. D. (2013). An ecosystem services approach to estimating economic losses associated with drought. *Ecological Economics, 91*, 19-27. https://doi.org/10.1016/j.ecolecon.2013.03.022

This paper presents an ecosystem services approach to estimating the total economic losses associated with droughts, with the goal of providing a consistent methodology to compare across locations and times. The methodology is applied to analysis of the Millennium Drought in the South Australian portion of the Murray–Darling Basin.

Cooper, S. D., Klose, K., Herbst, D. B., White, J., Drenner, S. M. & Eliason, E. J. (2021). Wildfire and drying legacies and stream invertebrate assemblages. *Freshwater Science, 40*(4), 659-680. https://doi.org/10.1086/717416

This study examines the effects of drought and wildfire on stream invertebrate communities. The authors sampled stream reaches with surface water in 2016, at the end of a five-year drought, and stream reaches in 2017, after flows resumed, including sites within (burned), outside (unburned), and downstream of footprints for fires occurring eight to 10 years previously. Data suggest the importance of protecting water supplies and riparian vegetation for perennial, shaded headwater reaches, which provide refuges from drought and wildfire for native biodiversity.

Crausbay, S. D., Betancourt, J., Bradford, J., Cartwright, J., Dennison, W. C., Dunham, J., Enquist, C. A. F., Frazier, A. G., Hall, K. R., Littell, J. S., Luce, C. H., Palmer, R., Ramirez, A. R., Rangwala, I., Thompson, L., Walsh, B. M., & Carter, S. (2020). Unfamiliar territory: Emerging themes for ecological drought research and management. *One Earth, 3*(3), 337-353. https://doi.org/10.1016/j.oneear.2020.08.019

The authors identify emerging issues in ecological drought that represent key challenges to timely and effective responses in order to provide a roadmap to facilitate the research and management innovations that will support forward-looking, co-developed approaches to reduce the risk of drought. Three emerging themes that need immediate attention are novel drought conditions, transformational drought impacts, and anticipatory drought management.

Crausbay, S. D., Ramirez, A. R., Carter, S. L., Cross, M. S., Hall, K. R., Bathke, D. J., Betancourt, J. L., Colt, S., Cravens, A. E., Dalton, M. S., Dunham, J. B., Hay, L. E., Hayes, M. J., McEvoy, J., McNutt, C. A., Moritz, M. A., Nislow, K. H., Raheem, N., & Sanford, T. (2017). Defining ecological drought for the twenty-first century. *Bulletin of the American Meteorological Society, 98*(12), 2543–2550. https://doi.org/10.1175/BAMS-D-16-0292.1

The authors define ecological drought as an episodic deficit in water availability that drives ecosystems beyond thresholds of vulnerability, impacts ecosystem services, and triggers feedbacks in natural and/or human systems. They introduce a framework for ecological drought that is organized along two dimensions: the components of vulnerability and a continuum from human to natural factors.

Cravens, A. E., Henderson, J., Friedman, J., Burkardt, N., Cooper, A. E., Haigh, T., Hayes, M., McEvoy, J., Paladino, S., Wilke, A. K., & Wilmer, H. (2021). A typology of drought decision making: Synthesizing across cases to understand drought preparedness and response actions. *Weather and Climate Extremes, 33,* Article 100362. https://doi.org/10.1016/j.wace.2021.100362

This paper synthesizes insights from 10 in-depth case studies to understand key facets of decision-making about drought preparedness and response. The authors present a typology with four elements that collectively describe how decisions about drought preparedness and response are made, providing a framework for a system-level understanding of how and by whom complex decisions about drought management are made.

Cravens, A. E., McEvoy, J., Zoanni, D., Crausbay, S., Ramirez, A., & Cooper, A. E. (2021). Integrating ecological impacts: Perspectives on drought in the Upper Missouri Headwaters, Montana, United States. *Weather, Climate, and Society, 13*(2), 363-376. https://doi.org/10.1175/WCAS-D-19-0111.1

This paper examines the extent to which professionals involved in drought preparedness and response perceive ecological drought in the Upper Missouri Headwaters basin in southwestern Montana. The results suggest that interviewees have an integrated understanding of drought, but tend to emphasize either ecological or nonecological impacts of drought; view drought as a problem driven by both human and natural factors; and believe that adaptive capacity is both helped and hindered by institutional, cultural, and economic factors, as well as by available information and past resource management practices.

Diffenbaugh, N. S., & Ashfaq, M. (2010). Intensification of hot extremes in the United States. *Geophysical Research Letters, 37*(15), Article L15701. https://doi.org/10.1029/2010GL043888

The authors use a suite of climate model experiments, finding that substantial intensification of hot extremes could occur within the next decades. The possibility that intensification of hot extremes could result from relatively small increases in greenhouse gas concentrations suggests that constraining global warming to two degrees Celsius may not be sufficient to avoid dangerous climate change.

Dunham, J. B., Angermeier, P. L., Crausbay, S. D., Cravens, A. E., Gosnell, H., McEvoy, J., Moritz, M. A., Raheem, N., & Sanford T. (2018). Rivers are social–ecological systems: Time to integrate human dimensions into riverscape ecology and management. *WIREs Water, 5*(4), Article e1291. https://doi.org/10.1002/wat2.1291

The authors discuss the need to emphasize feedbacks between social and ecological processes to understand rivers as social-ecological systems, and argue that conservation successes within riverscapes may not come from better ecological science, improved ecosystem service analyses, or economic incentives if the fundamental drivers of human behaviors are not understood and addressed in conservation planning and implementation.

Gleick, P. H., & Cooley, H. (2021). Freshwater scarcity. *Annual Review of Environment and Resources, 46*, 319-348. https://doi.org/10.1146/annurev-environ-012220-101319

This paper provides an overview of the causes and consequences of water scarcity, the limitations of methods for projecting water demands and measuring water scarcity, and approaches for addressing water scarcity. The authors emphasize that addressing scarcity requires moving beyond reliance on traditional supply-side solutions to implement more comprehensive and integrated solutions that include alternative water supply options, expanded water efficiency and demand management approaches, and more sophisticated institutional and economic policies.

Klasic, M., Fencl, A., Ekstrom, J. A., & Ford, A. (2022). Adapting to extreme events: Small drinking water system manager perspectives on the 2012–2016 California drought. *Climatic Change, 170*(3), 1-25. https://doi.org/10.1007/s10584-021-03305-8

This study documents small drinking water system managers' experiences during the 2012 to 2016 drought in California, finding that systems that built technical, managerial, or financial capacity prior to the drought were at an advantage over systems that lacked this capacity, and that there is a dearth of adaptation planning among small water systems.

Lund, J., Medellín-Azuara, J., Durand, J., and Stone, K. (2018). Lessons from California's 2012–2016 drought. *Journal of Water Resources Planning and Management, 144*(10), Article 04018067. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000984

This paper summarizes the magnitude and impacts of the 2012 to 2016 California drought and discusses innovations in water management and lessons learned, noting that water management was unusually effective in that drought, with the exception of water management for ecosystems and rural drinking water supplies.

McEvoy, J., Bathke, D. J., Burkardt, N., Cravens, A. E., Haigh, T., Hall, K. R., Hayes, M. J., Jedd, T., Poděbradská, M., & Wickham, E. (2018). Ecological drought: Accounting for the non-human impacts of water shortage in the Upper Missouri Headwaters basin, Montana, USA. *Resources, 7*(1), Article 14. https://doi.org/10.3390/resources7010014

The authors analyze five watershed-scale drought plans in southwestern Montana to understand if, and how, the ecological impacts of drought are currently being assessed. The analysis revealed that all five plans consider some ecological impacts, but that the scope of impacts mentioned is generally limited to fish populations and fish habitat as monitored through streamflows and water temperatures, which have limitations.

Nover, D. M., Dogan, M. S., Ragatz, R., Booth, L., Medellín-Azuara, J., Lund, J. R., & Viers, J. H. (2019). Does more storage give California more water? *Journal of the American Water Resources Association, 55*(3), 759-771. https://doi.org/10.1111/1752-1688.12745

This paper examines the value of expanding surface reservoir capacity in California using hydroeconomic modeling for historical conditions, a future warm-dry climate, and California's recently adopted policy to end groundwater overdraft. Results show expanding surface storage capacity rarely provides sizable economic value in most of California.

Pinter, N., Lund, J., & Moyle, P. (2019). The California water model: Resilience through failure. *Hydrological Processes, 33*(12), 1775–1779. https://doi.org/10.1002/hyp.13447

This paper argues that the success of California's water model rests on its past failures, from which local, regional, and state agencies and water users have learned and adapted.

Raheem, N., Cravens, A. E., Cross, M. S., Crausbay, S., Ramirez, A., McEvoy, J., Zoanni, D., Bathke, D. J., Hayes, M., Carter, S., Rubenstein, M., Schwend, A., Hall, K., & Suberu, P. (2019). Planning for ecological drought: Integrating ecosystem services and vulnerability assessment. *WIREs Water, 6*(4), Article e1352. https://doi.org/10.1002/wat2.1352

To incorporate ecological impacts into drought planning in the Upper Missouri Headwaters region in Montana, the authors combine ecosystem services elicitation, using the Common International Classification of Ecosystem Services, and a vulnerability assessment using semi-structured interviews. Results suggest that a combination of open-ended vulnerability assessment methods and ecosystem services elicitation using a structured framework can result in greater understanding of ecological drought vulnerability in a given region.

Roche, J. W., Ma, Q., Rungee, J., & Bales, R. C. (2020). Evapotranspiration mapping for forest management in California's Sierra Nevada. *Frontiers in Forests and Global Change, 3,* Article 69. https://doi.org/10.3389/ffgc.2020.00069

This paper assesses the response of two densely forested watersheds in the Sierra Nevada to forest disturbance and climate variability by studying how past wildfires changed forest evapotranspiration and what past evapotranspiration patterns imply for the availability of subsurface water storage for drought resistance.

Rohde, M. M., Biswas, T., Housman, I. W., Campbell, L. S, Klausmeyer, K. R., and Howard, J. K. (2021). A machine learning approach to predict groundwater levels in California reveals ecosystems at risk. *Frontiers in Earth Science, 9,* Article 784499. https://doi.org/10.3389/feart.2021.784499

This study uses satellite-based remote sensing to predict groundwater levels under groundwater dependent ecosystems across California. The results indicate that declining shallow groundwater levels may be adversely impacting California's groundwater dependent ecosystems, particularly where groundwater levels have fallen beneath plant roots or streams thereby affecting key life processes or hydrological processes.

Rohde, M. M., Stella, J. C., Roberts, D. A., & Singer, M. B. (2021). Groundwater dependence of riparian woodlands and the disrupting effect of anthropogenically altered streamflow. *Proceedings of the National Academy of Sciences, 118*(25), Article e2026453118. https://doi.org/10.1073/pnas.2026453118

Analysis in this paper suggests that many riparian ecosystems have become reliant on anthropogenically altered flow regimes, making them more vulnerable and less resilient to rapid hydrologic change, potentially leading to future riparian forest loss across increasingly stressed dryland regions.

Saito, L., Christian, B., Diffley, J., Richter, H., Rohde, M. M., & Morrison, S. A. (2021). Managing groundwater to ensure ecosystem function. *Groundwater, 59*(3), 322-333. https://doi.org/10.1111/gwat.13089

This paper describes minimum provisions for planning, managing, and monitoring groundwater that collectively can lower the risk of harm to groundwater-dependent ecosystems and species, with a special emphasis on arid systems, where ecosystems and species may be especially reliant upon and sensitive to groundwater dynamics.

Steinemann, A. (2014). Drought information for improving preparedness in the western states. *Bulletin of the American Meteorological Society, 95(*6), 843-847. https://doi.org/10.1175/BAMS-D-13-00067.1

This article provides results and insights from a survey of state drought managers in the 19 Western Governors' Association States that investigated their drought concerns and impacts, the use and value of drought plans, and the types of early warning information that could inform decisions and reduce drought damages.

Stevenson, S., Coats, S., Touma, D., Cole, J., Lehner, F., Fasullo, J., & Otto-Bliesner, B. (2022). Twenty-first century hydroclimate: A continually changing baseline, with more frequent extremes. *Proceedings of the National Academy of Sciences, 119*(12), Article e2108124119. https://doi.org/10.1073/pnas.2108124119

The authors analyze large climate model ensembles to find that the risk of droughts and pluvial states relative to expected changing baseline conditions is fairly similar to the 20th century risk; by continually adapting to long-term background changes, these risks could possibly be minimized. However, increases in the frequency of extremely wet and dry years are still present even after removing background trends, indicating that sustainably managing hydroclimate-driven risks in a warmer world will face increasingly difficult challenges.

Ulibarri, N., & Scott, T. A. (2019). Environmental hazards, rigid institutions, and transformative change: How drought affects the consideration of water and climate impacts in infrastructure management. *Global Environmental Change, 59,* Article 102005. https://cpb-us-e2.wpmucdn.com/faculty.sites.uci.edu/dist/6/598/files/2019/11/UlibarriScott_2019_GEC_AM.pdf

This paper uses the 2012 to 2016 California drought to assess whether it yielded a shift in institutional norms, namely in agency application of existing regulations toward enhanced socio-ecological resilience in the face of climate change. The results suggest that it is challenging for slow-onset hazards to yield shifts in institutional norms.

van Dijk, A. I. J. M., Beck, H. E., Crosbie, R. S., de Jeu, R. A. M., Liu, Y. Y., Podger, G. M., Timbal, B. & Viney, N. R. (2013). The Millennium Drought in southeast Australia (2001–2009): Natural and human causes and implications for water resources, ecosystems, economy, and society. *Water Resources Research, 49*(2), 1040-1057. https://doi.org/10.1002/wrcr.20123

The authors isolate and quantify anthropogenic and natural contributions to Australia's Millennium Drought and its impacts. Data indicates that humans cannot predict what the

next drought will look like because each drought is unique, which makes it difficult to plan for droughts, even though they occur regularly.

Welle, P. D., Medellín-Azuara, J., Viers, J. H., & Mauter, M. S. (2017). Economic and policy drivers of agricultural water desalination in California's central valley. *Agricultural Water Management, 194*, 192-203. https://doi.org/10.1016/j.agwat.2017.07.024

This study assesses the public and private costs and benefits of distributed desalination in the Central Valley. Water desalination is only likely to be profitable in four percent of the Central Valley during periods of severe drought, and current costs would need to decrease by 70 to 90% for adoption to occur on the median acre.

Wheeler, S. A. (2014). Insights, lessons and benefits from improved regional water security and integration in Australia. *Water Resources and Economics, 8*, 57-78. https://doi.org/10.1016/j.wre.2014.05.006

This paper provides an overview of the major water policy reforms in the Murray-Darling Basin in Australia and reviews the identified benefits and costs of its 2012 Basin Plan. The results signal that the quantified benefits of the Plan may outweigh the costs by up to three times. However, there are lessons to be learned from the extensive consultation, valuation and compensation paths that were adopted in Australia.

Williams, A. P., Cook, B. I., & Smerdon, J. E. (2022). Rapid intensification of the emerging southwestern North American megadrought in 2020–2021. *Nature Climate Change, 12*, 232–234. https://doi.org/10.1038/s41558-022-01290-z

Analyzing soil moisture, the authors demonstrate that after exceptional drought severity in 2021, approximately 19% of which is attributable to anthropogenic climate trends, 2000 to 2021 was the driest 22-year period since at least 800 CE.

Government Reports

California Department of Water Resources. (2010). *California drought contingency plan*. https://drought.unl.edu/archive/plans/Drought/state/CA_2010.pdf

In response to an Executive Order from Governor Schwarzenegger during the 2008 to 2009 drought, the Department of Water Resources developed this Drought Contingency Plan containing strategies and actions State agencies may take to prepare for, respond to, and recover from droughts.

California Department of Water Resources. (2019). *California water plan update 2018.* https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/Update2018/Final/California-Water-Plan-Update-2018.pdf

The California Water Plan is the State's strategic plan for sustainably managing and developing water resources for current and future generations, presenting the status and trends of the state's water-dependent natural resources; water uses and supplies; and future agricultural, urban, and environmental water demands and supplies for a range of plausible climate and socio-economic scenarios. The plan is intended to guide State investments in innovation and infrastructure, and advance integrated watershed management with sustainable outcomes.

California Department of Water Resources. (2020). *California's most significant droughts: Comparing historical and recent conditions.* https://water.ca.gov/-/media/DWR-Website/Web-Pages/What-We-Do/Drought-Mitigation/Files/Publications-And-Reports/CalSigDroughts19_v9_ay11.pdf

This report examines and compares the conditions of recent and historical droughts in California, noting that understanding the impacts historically observed and lessons learned in our past large droughts can help Californians be better prepared for future droughts.

California Department of Water Resources. (2021). *California's drought of 2012-2016: An overview.* https://water.ca.gov/-/media/DWR-Website/Web-Pages/Water-Basics/Drought/Files/Publications-And-Reports/033021_2012-16-Drought-Report_v4_ay11.pdf

This report documents drought conditions and impacts experienced during the statewide drought of Water Years 2012 to 2016. The report's focus is on water supply conditions and related information for urban and agricultural uses, together with a review of the associated impacts.

California Department of Water Resources. (2021). *Small water systems and rural communities drought and water shortage contingency planning and risk assessment*. https://water.ca.gov/Programs/Water-Use-And-Efficiency/2018-Water-Conservation-Legislation/County-Drought-Planning

The Department of Water Resources was directed to identify small water suppliers and rural communities that may be at risk of drought and water shortage vulnerability, and to propose recommendations and information in support of improving their drought preparedness. The report is published in two parts: Part I deals with drought and water shortage contingency planning recommendations, and Part II presents a methodology of drought and water shortage vulnerability assessment and risk scoring.

California Governor's Office of Emergency Services. (2018). *2018 state of California hazard mitigation plan.* https://www.caloes.ca.gov/wp-content/uploads/002-2018-SHMP_FINAL_ENTIRE-PLAN.pdf

The State Hazard Mitigation Plan is the State's hazard mitigation guidance document and provides an updated and comprehensive description of California's historical and current hazard analysis, mitigation strategies, goals, and objectives. It addresses a number of hazards, including drought.

California Governor's Office of Planning and Research, California Natural Resources Agency, and California Energy Commission. (2018). *California's fourth climate change assessment.* https://climateassessment.ca.gov/

The Fourth Climate Change Assessment is part of California's comprehensive strategy to take action based on cutting-edge climate research. While California is leading efforts to reduce greenhouse gas emissions, the State must also proactively address current and future impacts of climate change.

California Natural Resources Agency. (2021). *Report to the legislature on the 2012–2016 drought: As required by chapter 340 of 2016*. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Water-Basics/Drought/Files/Publications-And-Reports/CNRA-Drought-Report-final-March-2021.pdf

This report provides an assessment of State government actions during the 2012 to 2016 drought, establishing a detailed record of actions taken. It highlights where California needs to build its resilience and suggests ways to better endure future dry years.

California State Water Resources Control Board. (2021). *Water rights drought effort review.* https://www.waterboards.ca.gov/board_info/agendas/2021/feb/warder_projectrpt_v2_508drft_210205.pdf

This report presents a compilation of comments from water users and managers on previous drought efforts and recommendations for future improvements. Outreach was specifically focused on water rights activities, and participant comments and recommendations generally fell into four main categories: communication, legal and policy issues, data, and collaboration.

California State Water Resources Control Board. (2022). *2022 drinking water needs assessment.* https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/2022needsassessment.pdf

This needs assessment identifies communities in California that are failing or at risk of failing to have access to safe drinking water, estimates the cost of implementing solutions for these communities, and identifies affordability challenges that may pose as barriers to implementing these solutions.

Doolan, J. (2016). *Building resilience to drought: The millennium drought and water reform in Australia.* The Australian Water Partnership. https://waterpartnership.org.au/wp-content/uploads/2016/08/AWN-Building-Resilience-to-Drought.pdf

This report discusses the relationship between drought and water reform in Australia, finding that in general, the economic and social consequences of the Millennium Drought were less severe because of water reforms put in place. In most cases, the actions taken during the drought accelerated and embedded much of the water reform agenda and built resilience to drought. However, the prospect of climate change means there is still significant ongoing work to be done to further improve water-use efficiency and build greater drought resilience in all sectors.

Green-Nylen, N., Kiparsky, M., Owen, D., Doremus, H., & Hanemann, M. (2018). *Addressing institutional vulnerabilities in California's drought water allocation: Part 2: Improving water rights administration and oversight for future droughts.* California's Fourth Climate Change Assessment. https://www.energy.ca.gov/sites/default/files/2019-12/Water_CCCA4-CNRA-2018-010_ada.pdf

This report advances the understanding of how the State Water Resources Control Board could approach proactively improving water rights administration and oversight for future droughts by exploring the possibility of adopting a contingency-based framework to support drought decision making and implementing a suite of complementary actions to reduce uncertainty and lay the groundwork for more timely and effective drought response.

State of Victoria Department of Environment, Land, Water and Planning. (2016). *Managing extreme water shortage in Victoria: Lessons from the Millennium Drought.* https://www.water.vic.gov.au/__data/assets/pdf_file/0017/512720/DELWP-MillenniumDrought-web-SB.pdf.pdf

This report documents the lessons learned and challenges faced by water managers in Victoria, Australia during the Millennium Drought. Conclusions include that Victoria's water sector is well placed to manage future water shortages because of the reforms to its water entitlement regime, water supply systems, and water resource planning processes that occurred in response to the drought. However, the uncertainty surrounding future conditions means that planning needs to be based on a wide range of plausible future climate scenarios.

Non-Government Organization and Think Tank Reports

Brill, G., Bielawski, A., Chapagain, A., Cooley, H., Diringer, S., Gleick, P., McNeeley, S., & Morrison, J. (2021). *Water resilience: Definitions, characteristics, relationships to existing concepts, and a call to action for building a water resilient future.* Pacific Institute. https://pacinst.org/wp-content/uploads/2021/10/Water-Resilience-Issue-Brief-Pacific-Institute-Oct-2021.pdf

This issue brief defines water resilience, identifies common characteristics of resilient water systems, urges water decisionmakers across the public and private sectors to commit to achieving water resilience by rapidly scaling solutions through policy and practice uptake. The Pacific Institute notes that, while implementation will differ by context, its work is focused on building water resilience alongside water security and sustainability through three programmatic areas: water efficiency and reuse; nature-based solutions; and water, climate, and social equity.

Colvin, C., Muruven, D., Lindley, D., Gordon, H., & Schachtschneider, K. (2016). *Water: Facts and futures, rethinking South Africa's water future.* World Wildlife Fund. http://awsassets.wwf.org.za/downloads/wwf009_waterfactsandfutures_report_web__lowres_.pdf

The report provides an overall summary of the current state and potential future of water in South Africa, including water supplies for people, the environment, and wastewater and sanitation.

Cooley, H., & Phurisamban, R. (2016). *The cost of alternative water supply and efficiency options in California*. Pacific Institute. https://pacinst.org/wp-content/uploads/2018/07/PI_TheCostofAlternativeWaterSupplyEfficiencyOptionsinCA.pdf

This study examines the net costs of stormwater capture, recycled water, brackish and seawater desalination, and a set of water conservation and efficiency measures. Findings indicate that urban water conservation and efficiency measures offer significant water savings and are the most cost-effective ways to meet current and future water needs. Of the water supply measures studied, large stormwater capture projects are among the least expensive and seawater desalination is the most expensive. Leak detection in the water distribution system is also highly cost-effective.

Cooley, H., Phurisamban, R., & Gleick, P. (2019). *The cost of alternative urban water supply and efficiency options in California.* Pacific Institute. https://iopscience.iop.org/article/10.1088/2515-7620/ab22ca/pdf

The contents and findings of this paper are largely the same as the previous resource listed above, but costs are calculated for cubic meters of water rather than acre-feet.

Cooley, H., Thebo, A., Abraham, S., Shimabuku, M., Gleick, P., & Diringer, S. (2022). *The untapped potential of California's urban water supply: Water efficiency, water reuse, and stormwater capture.* Pacific Institute. https://pacinst.org/wp-content/uploads/2022/04/PI_California_Untapped_Urban_Water_Potential_2022-1.pdf

This assessment finds that urban water-use efficiency improvements could reduce statewide urban water use by 2.0 million to 3.1 million acre-feet per year (AFY). The reuse potential of municipal wastewater is 1.8 million to 2.1 million AFY, and the stormwater capture potential is 580,000 AFY in a dry year to as much as 3.0 million AFY in a wet year. Previous assessments have shown that these efficiency and supply options are more cost effective than traditional options to expand supply.

Feinstein, L., Phurisamban, R., Ford, A., Tyler, C., & Crawford, A. (2017). *Drought and equity in California.* Pacific Institute. https://pacinst.org/wp-content/uploads/2017/01/PI_DroughtAndEquityInCA_Jan_2017.pdf

This report examines three major impacts of the 2012 to 2016 California drought. The first two, supply shortages and rising costs, affected people's access to safe, affordable water in their homes. The authors also investigated the impacts of the drought on salmon and, by extension, commercial and tribal fishermen reliant on salmon for income, food, and cultural traditions. Findings indicate that low-income households, people of color, and communities already burdened with environmental pollution suffered the most severe impacts.

Gartrell, G., Mount, J., & Hanak, E. (2022). *Tracking where water goes in a changing Sacramento–San Joaquin Delta.* Public Policy Institute of California. https://www.ppic.org/wp-content/uploads/policy-brief-tracking-where-water-goes-in-a-changing-sacramento-san-joaquin-delta.pdf

This policy brief provides an overview of changes in runoff and water use that are being experienced in the Sacramento-San Joaquin Delta. The authors suggest that, to better cope with more intense droughts, management of the Delta and its watershed would benefit from a suite of improvements in water use tracking and oversight, updates in water flow and quality regulations, and cost-effective investments to store more water in wet years.

Gartrell, G., Mount, J., Hanak, E, & Gray, B. (2017). *A new approach to accounting for environmental water: Insights from the Sacramento–San Joaquin Delta*. Public Policy Institute of California. https://www.ppic.org/wp-content/uploads/r_1117ggr.pdf

This report reviews California's long-standing methods for defining and accounting for environmental water and proposes reforms to improve the timeliness, transparency, and detail in the accounting of environmental water allocation.

Hanak, E., Escriva-Bou, A., Mount, J., Pottinger, L., Ayres, A., Bardeen, S., Collins, J., Gray, B., McCann, H., Peterson, C., Rosser, A., & Sencan, G. (2021). *Priorities for California's water: Responding to the changing climate.* Public Policy Institute of California. https://www.ppic.org/wp-content/uploads/priorities-for-californias-water-november-2021.pdf

This brief examines how the current drought and a changing climate are affecting California's ability to manage water and lays out priority actions to address major challenges—including some urgent short-term actions should the drought continue into next year.

Hanak, E., Mount, J., Chappelle, C., Lund, J., Medellín-Azuara, J., Moyle, P., & Seavy, N. (2015). *What if California's drought continues?* Public Policy Institute of California. https://www.ppic.org/wp-content/uploads/content/pubs/report/R_815EHR.pdf

This report assesses impacts of and responses to California's 2012 to 2016 drought, which the authors suggest served as a dry run for future long-term droughts. Findings indicate that although no sector was untouched, impacts varied greatly, reflecting different levels of drought preparedness. To respond to long-term droughts emergency, programs will need to be significantly expanded to get drinking water to rural residents and to prevent major losses of waterbirds and extinctions of numerous native fish species, including most salmon runs. California also needs to start a longer-term effort to build drought resilience in the most vulnerable areas.

Lee, C., Harder, J., Frank, R., Thompson, B., Doduc, T., Doremus, H., & Pannu, C. (2022). *Updating California water laws to address drought and climate change.* Planning and Conservation League. https://www.pcl.org/media/2022/02/Updating-California-Water-Laws-to-Address-with-Drought-and-Climate-Change.pdf

This report argues that California's water laws need to be reassessed to address today's challenges, safeguard the health, safety, and livelihoods of California's 40 million residents, support its economy, and protect its imperiled ecosystems. To develop this report, the Planning and Conservation League assembled a group of California water law and policy experts to help develop new recommendations, taking into account the unprecedented conditions facing 21st century California.

Marcus, F. (2022). *State climate policy and nature-based solutions: A match that provides multiple benefits for climate, water, and more.* Stanford Water in the West. https://waterinthewest.stanford.edu/sites/default/files/Woods%20WitW%20Climate%20Policy%204-page%20Summary%20v06%20WEB%20%282%29.pdf

This brief suggests that significant opportunities exist to combine climate policy and nature-based solutions. These opportunities have the potential to yield multiple societal and environmental benefits, including water benefits, but need focused attention to realize their potential. Ecologically-based forest restoration, wet or mountain meadow restoration, "healthy soils," and other agricultural practices can yield these multiple benefits.

Mount, J., Gray, B., Börk, K., Cloern, J., Davis, F., Grantham, T., Grenier, L., Harder, J., Kuwayama, Y., Moyle, P., Schwartz, M., Whipple, A., & Yarnell, S. (2019). *A path forward for California's freshwater ecosystems*. Public Policy Institute of California. https://www.ppic.org/publication/a-path-forward-for-californias-freshwater-ecosystems/

The authors recommend that the State adopt the principles and practices of ecosystem-based management, which involves the simultaneous management of water, land, and organisms to achieve a desired ecosystem condition that benefits both native biodiversity and human well-being.

Mount, J., Gray, B., Chappelle, C., Doolan, J., Grantham T., & Seavy, N. (2016). *Managing water for the environment during drought: Lessons from Victoria, Australia.* Public Policy Institute of California. https://www.ppic.org/wp-content/uploads/content/pubs/report/R_616JMR.pdf

This report examines Victoria, Australia's response to extreme drought, focusing on the development of policies for managing environmental water, and compares these policies to those of California. This comparison highlights some key lessons learned by Victoria that may help guide how California adapts environmental water management to address future droughts.

Mount, J., Gray, B., Chappelle, C., Gartrell, G., Grantham, T., Moyle, P., Seavy, N., Szeptycki, L., & Thompson, B. (2017). *Managing California's freshwater ecosystems: Lessons from the 2012-16 drought.* Public Policy Institute of California. https://www.ppic.org/wp-content/uploads/r_1117jmr.pdf

The authors' review of eight case studies on environmental water management during the 2012 to 2016 drought reveal both strengths and weaknesses in federal, state, and local response that can inform how California addresses future droughts. Three areas of reform hold promise for improving ecosystem conditions and reducing conflict: improve water accounting, prepare for drought, and develop ecosystem water budgets.

Mount, J., Hanak, E., Lund, J., Ullrich, P., Baerenklau, K., Butsic, V., Chappelle, C., Escriva-Bou, A., Fogg, G., Gartrell, G., Grantham, T., Gray, B., Green, S., Harter, T., Jezdimirovic, J., Jin, Y., McCann, H., Medellín-Azuara, J., Mitchell, D., … Xu, Z. (2018). *Managing drought in a changing climate: Four essential reforms.* Public Policy Institute of California. https://www.ppic.org/wp-content/uploads/managing-drought-in-a-changing-climate-four-essential-reforms-september-2018.pdf

This report argues that a more focused plan of action is needed to enable the water system to adapt to greater climate extremes and water scarcity and avoid unwanted consequences of drought. Key reforms include to plan ahead, update the water grid, update water allocation rules, and find reliable funding. Successful adaptation will require strong leadership at the state and local levels, and cooperation on all fronts

Nelson, B. (2022). *Building blocks: Tools and lessons for designing a block of water for the environment.* Defenders of Wildlife. https://defenders.org/sites/default/files/2022-07/Building%20Blocks%20White%20Paper%20Final%207-12-22.pdf

This white paper provides a guide for efforts seeking to create an environmental block of water by laying out a series of questions that should be answered in the process of creating a new environmental water program.

Null, S., Mount, J., Brian Gray, Dybala, K., Sencan, G., Sturrock, A., Thompson, B., & Zeff, H. B. (2022). *Storing water for the environment: Operating reservoirs to improve California's freshwater ecosystems.* Public Policy Institute of California. https://www.ppic.org/publication/storing-water-for-the-environment/

This report argues that California needs a new approach for managing environmental water in its large reservoirs, particularly as the climate warms and droughts become more intense, and makes recommendations for such an approach.

Shimabuku, M., & Kammeyer, C. (2022). *Left out in drought: California fish.* Pacific Institute. https://pacinst.org/publication/left-out-in-drought-california-fish-2022/

This report highlights the significant and persistent threats of the current drought, and the associated policy and management responses, to fish and to freshwater ecosystems more broadly, focusing on drought impacts on fish in the Sacramento River, San Joaquin River, and San Francisco Bay-Delta. The authors' goal is to expedite improved management responses by informing communities and policymakers of the severity of the drought's impact on aquatic ecosystems, and by recommending strategies and solutions that build drought-resilient water systems now and for generations to come.

Szinai, J., Abraham, S., Cooley, H., & Gleick, P. (2021). *The future of California's water-energy-climate nexus.* Pacific Institute. https://pacinst.org/wp-content/uploads/2021/09/Water-Energy-Report_Sept-2021.pdf

This report finds that without urgent water efficiency measures, carbon emissions associated with water usage in California are likely to spike in coming years, as changing sources of water supply and population growth drive up energy-intensive urban and agricultural water needs. The report identifies specific water policies that could play an important role in helping the state meet energy and greenhouse gas emissions goals.

Turner, A., White, S., Chong, J., Dickinson, M.A., Cooley, H., & Donnelly, K. (2016). *Managing drought: Learning from Australia.* Pacific Institute. https://pacinst.org/wp-content/uploads/2016/02/Managing-Drought-Report-2016-02-23-FINAL-US-Letter.pdf

This research reflects on some of the key lessons from the Australian Millennium Drought experience in order to assess the opportunities for California. The report provides a resource for Californian water planners and managers as the state grapples with drought and seeks to build resilient and sustainable water systems and provides an overview of the key events and initiatives implemented in Australia's four largest cities.

Woodhouse, C., Meko, D., Bigio, E., & Frederick, S. (2017). *Using tree-ring records for understanding droughts in a long-term context: A guidebook.* Climate Assessment for the Southwest. https://cwoodhouse.faculty.arizona.edu/sites/cwoodhouse.faculty.arizona.edu/files/So%20Cal%20GuidebookLR.pdf

This guidebook introduces water resource managers to extended records of streamflow and precipitation developed using tree-ring data, and to demonstrates how these data provide insights on drought risk.

Other

Medellín-Azuara, J., Herman, J., Lund, J. R., Howitt, R. E., & Jenkins, M. W. (n.d.). *CALVIN.* University of California Davis. https://watershed.ucdavis.edu/shed/lund/CALVIN/

CALVIN is a hydro-economic optimization model of California's intertied water system. It is the only model representing the extensive statewide system in terms of supplies, demands, and physical and economic adaptability.

Meza, F., Vicuña, S., Melo, O., Orellana, S., Diaz, J. T., Canales, M., Medellín-Azuara, J., Herman, J., & Solis, S. S. (2017). *Water and climate change: Lessons for adaptation from a comparative analysis between Chile and California*. Centro de Cambio Global UC, Pontificia Universidad Catolica de Chile and Center for Watershed Sciences, University of California, Davis.

The objective of this paper is to characterize the main similarities and differences between Chile and California based on water availability, water use, and governance, and to analyze possible scenarios of climate change to extract lessons for the implementation of adaptation plans.

Börk, K., Rypel, A. L., Yarnell, S., Willis, A., Moyle, P. B., Medellín-Azuara, J., Lund, J., & Lusardi, R. (2022). *Considerations for developing an environmental water right in California.* California Water Blog. https://californiawaterblog.com/2022/06/12/considerations-for-developing-an-environmental-water-right-in-california/

This post from the California Water Blog, and the posts cited below, represent a sampling of the non-academic resources that were consulted as part of this effort.

Lund, J. (2014). *Why utilities shy from mandatory water saving during a drought.* California Water Blog. https://californiawaterblog.com/2014/07/30/why-utilities-shy-from-mandatory-water-saving-during-a-drought/

Lund, J. (2021). *Could California weather a mega-drought?* California Water Blog. https://californiawaterblog.com/2021/09/12/could-california-weather-a-mega-drought-2/

Lund, J. (2022). *Follow the water!* California Water Blog. https://californiawaterblog.com/2022/07/24/follow-the-water/

Lund, J., Hanak, E., Thompson, B., Gray, B., Mount, J. & Jessoe, K. (2022). *Why give away fish flows for free during a drought?* California Water Blog. https://californiawaterblog.com/2022/04/10/why-give-away-fish-flows-for-free-during-a-drought/

Lund, J., & Moyle, P. (2015). *Water giveaways during a drought invite conflict.* California Water Blog. https://californiawaterblog.com/2015/03/23/water-giveaways-during-a-drought-invite-conflict/