Title

Keeping Water in Climate-Changed Headwaters Longer

Journal
San Francisco Estuary and Watershed Science, 21(4)

Authors
Dettinger, Michael
Wilson, Anna
McGurk, Garrett

Publication Date
2023

DOI
10.15447/sfews.2023v21iss4art1

SFEWS San Francisco Estuary & Watershed Science: Science & Policy for the Delta

Keeping Water in Climate-Changed Headwaters Longer

Michael Dettinger*[1], Anna Wilson[1], Garrett McGurk[1]

SFEWS Volume 21 | Issue 4 | Article 1

https://doi.org/10.15447/sfews.2023v21iss4art1

* Corresponding author: *mddettinger@gmail.com*

1 Center for Western Weather and Water Extremes, Scripps Institution of Oceanography, University of California, San Diego La Jolla, CA 92093 USA

KEY WORDS

California, climate change, headwaters hydrology, water supply, forest restoration, beavers, forecast-informed reservoir operations, FIRO

Climate-change projections for California confidently describe a future with warmer temperatures, more evaporative demand, less snow, more rain, earlier and flashier runoff and streamflow, and drier summer conditions. The future of annual precipitation is much less certain, but a fairly unanimous projection of drier, more drought-prone conditions punctuated by occasional stronger-than-historical storms is almost as common among projections as is the warming itself. Rather than focusing on the less certain annual precipitation changes, we recommend more focus on keeping water in the headwaters longer. Doing so will involve reducing winter flood flows from headwater catchments, reducing the summer aridification (and wildfire risks) there, salvaging some groundwater recharge that would likely otherwise be lost, and overall, perpetuating headwater (and downstream) hydrologies under more historical and natural conditions.

CURRENT CLIMATE PROJECTIONS

Considering recent and current projections of what climate change will mean for California's water resources, the picture is grim. Warming will melt snows; expand areas that receive rainfall rather than snow; make storms and floods larger and wilder; dry out soils, vegetation, springs, lakes, and streams; and set the stage for notably larger and more intense droughts and wildfires.

At the same time, the average projection of future precipitation amounts (over the past several generations of projections) has largely hovered near historical norms, except in the southern ramparts of California, Arizona, and New Mexico, where most projections agree it will be drier. One climate model projects more precipitation overall, another projects less; and this pattern repeats through the modern collections of projections (e.g., Dettinger 2005, 2016; Gershunov et al. 2019). Similarly, multi-model averages predict somewhat wetter conditions in one generation and drier conditions in the next generation (as found by comparisons between projections used in the Second through Fifth National Climate Assessments (Karl et al. 2009; Melillo et al 2014; Wuebbles et al. 2017; Crimmins et al. 2023). Among the growing number of models from which projections are available, the predicted precipitation changes are small—fractionally wetter overall, or drier overall, but not vastly so in either direction. This equivocation is a source of consternation for climatologists and for those who manage water—and land—across the region. How can they plan and manage if the overall water availability from precipitation cannot be pinned down more definitely than this?

The tendency for precipitation projections to cluster with uncertainty around historical norms too often draws attention away from an important and common outcome in the projections. What the models agree on is that future precipitation will come in the form of reduced medium- to light-precipitation amounts (e.g., Dettinger 2016; Polade et al. 2017), and more dry days (Polade et al. 2014), all interrupted by occasional wetter-than-historical major storms and storm sequences (Dettinger et al. 2004; Pierce et al. 2013; Gershunov et al. 2019). Under these conditions—and together with trends away from snowfall and toward more rainfall—immediate surface runoff from those large storms is expected to increase, and the amount of water that makes its way down into slower, subsurface pathways will likely decline. In fact, climate models are nearly as unanimous in projecting increased large storms amid a background of more persistent and taxing dryness as they are in projecting a warmer future (Pierce et al. 2013; Polade et al. 2014; Dettinger 2016). The consistency in these predictions seems sufficient to guide policy.

AN APPEAL TO CALIFORNIA WATER AGENCIES AND INSTITUTIONS

The lesson to be taken from modern projections of future precipitation and hydrology is that we should probably not fixate on the continuing uncertainty about precisely which direction precipitation totals will skew. Instead, we must focus on the high likelihood that amounts of precipitation will change far less than the way that precipitation arrives; thus, we must prepare for a future of a few, much larger storms and—if left unmitigated—enhanced spikes of runoff in the winter and spring, rather than the long-term moderate flows in the warm seasons we have historically incorporated into water-resources planning. Considering this, the most pressing challenge posed by climate change in western headwaters can be more narrowly bounded. Instead of the challenge being "How can we prepare for a lot less water?" we can shift the focus to address the most immediate challenge, which is "How can we keep the water that arrives in the headwaters longer?" This essay is an appeal to California water agencies and institutions to consider applying additional adaptation strategies to retain water in the headwaters longer so that the challenges posed by changing climate and hydrologies that negatively affect the state's future water supplies and flood-risk management can be partially mitigated.

Headwaters provide many benefits. Surface water is critical for people, flora and fauna, and wildfire reduction (Gies 2022). Subsurface water is vital for forest health and even more widespread wildfire reduction (Gies 2022). Benefits downstream also will be crucial. Most western water supplies—including most major western reservoirs—have been developed based on historical expectations that much water will arrive well after the cold, wet season as spring and summer snowmelt, or that groundwater will always be available during drought. Keeping water in the headwaters longer can restore, in part, the important delays that historical snowpacks provided. Ensuring that more precipitation gets deep into subsurface pathways is probably one (albeit small) way of adding to future groundwater supplies.

Of course, it is easy to say, "We need to keep water in the headwaters longer." Actually doing so will undoubtedly be more complicated. Our purpose here is to shift focus from dire precipitation projections to mitigating mostly warming-induced headwater changes at watershed scales, and on intra-seasonal to event scales. A number of possible mitigating responses are already in the works in California for other reasons. Each of the following possibilities, along with others[1], could be evaluated, accelerated, or transformed to address climate-change effects on the state's headwaters. Here, we discuss several examples: (1) an increased emphasis on soils and percolation management as a priority and co-benefit in forest-health restoration activities; (2) beaver-population restoration or proliferation of beaver-inspired headwater infrastructures; and (3) upstream-focused, forecast-informed reservoir-operation (FIRO) strategies.

EXAMPLE STRATEGY 1: SOILS AND PERCOLATION MANAGEMENT

As discussed, approximately the same amount of precipitation is deposited in the headwaters in most climate projections. It just leaves the basin earlier, by way of more evaporation and floods, and in less convenient forms at less convenient times. In response, we need to consider and explore landscape and soil-surface treatments that encourage snowmelt, precipitation, and other accumulations of water to percolate into headwater soils. Because surface water is susceptible to evaporation from the headwaters, keeping the water in the headwaters longer

1. This essay reflects a narrower application of some of the issues and options for "slow water," as Gies (2022) extensively addresses. This essay focuses on California's water systems based solely on climate projections specific to California, taking into account the authors' particular specializations and this journal's core audience. We refer readers to Gies (2022) for a more comprehensive conversation.

https://doi.org/10.15447/sfews.2023v21iss4art1

involves getting the water below the surface to shield it from direct evaporation. Getting waters into soils faster and deeper also involves sending more of those waters into and along various subsurface pathways toward streams and springs. Subsurface flows are slower than surface runoff, so that, even though the water eventually makes its way into streams, it takes longer to reach them, thus keeping water in the headwaters longer.

Soil-surface treatments should be designed and undertaken and ideally "piggy-backed" with the coming forest-health treatments to reduce 20th-Century accumulations of fuel caused by wildfire suppression. Forest-health treatments, such as thinning, restoration of natural fire regimes, and so on, will require large investments of effort and money in the next few decades to forestall the ongoing rise of mega-fires throughout much of the state[2]. If soil-surface treatments can be designed to enhance interception and percolation of water, and then prioritized and layered within forest-health treatments—rather than treated as a coincidental benefit—then the scale of soil management needed to ensure that more precipitation and snowfall percolates deeper into subsurface soils of our headwaters seems more approachable. The resulting wetter soils also can contribute to forestalling or dampening wildfires.

Such actions are needed specifically to mitigate impacts on snowpack storage and rising evaporative demands. Snowpacks have historically acted as natural reservoirs that carry water over from winter precipitation to emerge months later as snowmelt in time for summer uses. California's spring snowpack typically contains amounts of water approximating three-quarters or more of the normal amount of water in its major man-made reservoirs. Much of California's water infrastructure was designed to make use of the natural reservoirs that its historical snowpacks form and, in the face of climate warming, replacing the diminishing snowpack reservoirs could require an almost doubling of current man-made-reservoir capacities (with all the difficulties that would involve). The transition from snowfall to rainfall and the hastening of runoff from earlier snowmelt, will also contribute to more immediate runoff and increased floods.

Later in the year, headwater soils, vegetation, and landscapes are projected to dry more because earlier snowmelt, a greater proportion of immediate rainfall runoff, and flashier storms accelerate runoff discharge from headwater catchments and ensure that waters will have long since exited before peak summer arrives (noted as early as Gleick 1987). Consequently, the more we can find ways to preserve or mimic the effects of historical snowpacks that keep more winter precipitation in the headwaters for 1 to 3 months longer, the more we can reduce water-supply effects of those snowpack losses.

Water that percolates into subsurface soils in the headwaters is not entirely protected from being returned to the atmosphere, of course. Trees and other

2. California may spend an estimated $1.5 billion and the federal government another $84 million per year on forest fuels management. See *https://resources.ca.gov/Newsroom/Page-Content/News-List/CA-Announces-$98-Million-In-Forest-Grants* and *https://www.ppic.org/blog/paying-for-forest-health-projects*

vegetation tap into subsurface waters to meet large evapotranspiration demands. In addition, warming is expected to increase the atmosphere's evaporative demand (i.e., the atmosphere's "thirstiness," McEvoy et al. 2020), which would increase the rates and amounts of water that evaporates or is used by vegetation per unit of water in the headwater soils.

Thus, other options for keeping waters in the headwaters longer are precisely those forest-health treatments (often forest thinning, McCann et al. 2020) mentioned earlier as a fiscal avenue to enable large-scale soil management. When forests are thinned, leaving fewer and more widely spaced trees and vegetation, there are effectively "fewer straws in the soda" so forest evapotranspiration can be reduced, and water remaining in the soils or making its way out to streams or into aquifers increases is increased (e.g., Guo et al. 2023). The task will be to ensure that forest-health treatments raise water percolation and storage benefits to the level of priorities rather than incidental outcomes.

EXAMPLE STRATEGY 2: BEAVERS

Regarding our second (less heavily engineered) strategy: consider that in the not-too-distant past, beavers were a widespread and important way that nature "kept water in the headwaters longer" (Goldfarb 2018; Dittbrenner et al. 2022; Larsen et al. 2021). Beavers, historically prevalent in the western states, were major ecosystem engineers and stored water behind their dams in many headwaters. Their behaviors enhanced groundwater recharge, slowed or reduced floods, enhanced summer water supplies, and subdued wildfires (Goldfarb 2018). However, as early as the 1700s, mountaineers followed by settlers began to extirpate beavers, so that California's mountain basins and ecosystems are now quite different from (and drier in general) than their pre-development condition. Re-establishment of beaver populations could help keep water in the headwaters longer. Beavers are single-minded and persistent in damming moving water anywhere they find it, but when they encounter human structures (or plans contrary to theirs) significant problems can ensue. Thus, engineers have invested in artificial beaver structures in some settings to try to recreate some of the benefits of beavers without the more annoying downsides of their behaviors (Pollock et al. 2014; Pierce et al. 2021; Gies 2022). The California Department of Fish and Wildlife is already beginning to scale up either the presence of beavers (and other natural allies) or restore some of their benefits by other means (and for a variety of reasons)[3]. Climate change provides yet one more reason to accelerate such efforts.

EXAMPLE STRATEGY 3: FIRO (FORECAST-INFORMED RESERVOIR OPERATIONS)

The third (and last) adaptation strategy we discuss here is a modification of reservoir operations to store more water in man-made reservoirs. One promising possibility is forecast-informed reservoir operations (FIRO; Jasperse et al. 2020).

3. *https://wildlife.ca.gov/Conservation/Mammals/Beaver*

https://doi.org/10.15447/sfews.2023v21iss4art1

FIRO uses modern weather and flood forecasts to make more and better decisions about when and how much water to release from existing reservoirs. FIRO offers opportunities for some reservoir operators to capitalize upon the combination of existing dams and infrastructure with modern forecast improvements—both already bought and paid for—to manage reservoir storage and releases to downstream users in ways that reduce downstream flood risks, or at least do not increase them at all. Capitalizing on these existing structures also allows more water to be stored longer in those reservoirs or recharged to aquifers (see Ralph et al. 2023), for later uses and environmental benefits. Recent studies in California have demonstrated that modern forecasts are already sufficiently accurate on time-scales of 5 or more days to allow more water to be stored safely in some reservoirs. Where FIRO is safer and more productive, traditional ways of increasing reservoir storage can be avoided, with considerable cost savings. More costly, traditional alternatives to FIRO include construction of entirely new dams, structural enhancements to existing dams, and dredging of some existing reservoirs to remove sediments that have partially filled the lakes since dam construction. All of these other options have major environmental limitations and costs.

To date, most FIRO feasibility studies have focused on downstream dams and reservoirs (Jasperse et al. 2020; Ralph et al. 2023). Even Lake Mendocino on the Russian River (where recent FIRO investigations began), albeit high in that river basin, has no other downstream dam that prevent its releases from reaching the ocean. If the aim is to keep water in the headwaters, new visions of FIRO could be evaluated that are implemented and integrated among the smaller and more diverse dams and reservoirs in or just below the headwaters. Current FIRO studies for Lake Oroville are focused entirely on the major reservoir *at the base* of the Feather River basin (Ralph et al. 2022). By contrast, the Feather River basin above Lake Oroville is one of the more heavily "plumbed" basins in California with many smaller dams, reservoirs, and pipelines used mostly to optimize hydropower generation (Koczot et al. 2005). The American River basin above Folsom Dam and reservoir and the upper San Joaquin River basin above Millerton Lake are other such basins that harbor many structures and options for managing headwaters' outflows to keep the water in them longer. Thus, rather than focusing FIRO investigations solely on the arrival and then releases of water that flow into the last reservoir before the waters leave source regions, additional strategies focused on upstream application of FIRO (U-FIRO) could be explored and tested for keeping water higher in the watersheds longer.

BENEFITS OF NEW STRATEGIES

Current projections of future precipitation in California and much of the western US—taken as a whole—are not the worst of the climate-change news. Rather, climate warming and its myriad interlinked effects are considerably more certain and more problematic for many western headwaters, including California's.

As presented here, more attention to the management and adaptation of California's headwaters at the state level could benefit California's overall climate-change-focused water resources planning. However, at present, the California Water Supply Strategy for adapting to a hotter, drier future does not include the words "headwater," "mountain," "meadow," or "forest"[4]. As California water agencies and institutions prepare their strategies and plans to secure the state's future water supplies and minimize flood risk, they would do well to consider how to keep water in the headwaters longer to mitigate inherent challenges posed by climate change.

REFERENCES

Crimmins AR, Avery CW, Easterling DR, Kunkel KE, Stewart BC, Maycock TK. 2023. Fifth National Climate Assessment. [Washington, DC]: US Global Change Research Program. Available from: *https://nca2023.globalchange.gov/downloads/*

Dettinger MD. 2005. From climate-change spaghetti to climate-change distributions for 21st Century California: San Franc Estuary Watershed Sci [accessed 2003 Dec 17];3(1). *https://doi.org/10.15447/sfews.2005v3iss1art6*

Dettinger MD. 2016. Historical and future relations between large storms and droughts in California. San Franc Estuary Watershed Sci [accessed 2003 Dec 17];14(2). *https://doi.org/10.15447/sfews.2015v14iss2art1*

Dettinger MD, Cayan DR, Meyer MK, Jeton AE. 2004. Simulated hydrologic responses to climate variations and change in the Merced, Carson, and American river basins, Sierra Nevada, California, 1900–2099: Climatic Change [accessed 2003 Dec 17];62:283-317. Available from: *https://link.springer.com/article/10.1023/B:CLIM.0000013683.13346.4f*

Dittbrenner BJ, Schilling JW, Torgersen CE, Lawler JJ. 2022. Relocated beaver can increase water storage and decrease stream temperature in headwater streams. Ecosphere [accessed 2022 Jul 22];13:e4168. *https://doi.org/10.1002/ecs2.4168*

Gerhunov A, Shulgina T, Clemesha R, Guirguis K, Pierce D, Dettinger M, Lavers D, Cayan D, Polade S, Kalansky J, Ralph FM. 2019. Precipitation regimes change in western North America—the role of atmospheric rivers. Nature Sci Rep [accessed 2003 Dec 17];9:9944. *https://doi.org/10.1038/s41598-019-46169-w*

Gies E. 2022. Water always wins—thriving in an age of drought and deluge. [Chicago (IL)]: University of Chicago Press. 344 p. Available from: *https://press.uchicago.edu/ucp/books/book/chicago/W/bo161589950.html*

Gleick PH. 1987. The development and testing of a water balance model for climate change impact assessment—modeling the Sacramento Basin. Water Resour Res [accessed 2003 Dec 17];23:1049–1061. *https://doi.org/10.1029/WR023i006p01049*

Goldfarb B. 2018. Eager—the surprising secret life of beavers and why they matter. [White River Junction (VT)]: Chelsea Green Publishing. 386 p.

4. *https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Water-Resilience/CA-Water-Supply-Strategy.pdf*

Guo H, Goulden M, Chung MG, Nyelele C, Egoh B, Keske C, Conklin M, Bales R. 2023. Valuing the benefits of forest restoration on enhancing hydropower and water supply in California's Sierra Nevada. Sci Tot Environ [accessed 2003 Dec 17];876:162836. *https://doi.org/10.1016/j.scitotenv.2023.162836*

Jasperse J, Ralph FM, Anderson M, Brekke L, Malasavage N, Dettinger MD, Forbis J, Fuller J, Talbot C, Webb R, Haynes A. 2020. Lake Mendocino Forecast Informed Reservoir Operations final viability assessment. [accessed 2003 Dec 17]. La Jolla (CA): University of California, San Diego. 141 p. Available from: *https://escholarship.org/uc/item/3b63q04n*

Karl TC, Melillo JM, Peterson TC. 2009. Global climate change impacts in the United States. [New York (NY)]: Cambridge University Press. 189 p.

Koczot KM, Jeton AE, McGurk B, Dettinger MD. 2005. Precipitation-runoff processes in the Feather River basin, northeastern California, with prospects for streamflow predictability. [accessed 2003 Dec 17]. US Geological Survey Scientific Investigations Report 2004-5202. 82 p. Available from: *https://pubs.usgs.gov/sir/2004/5202/*

Larsen A, Larsen JR, Lane SN, 2021. Dam builders and their works—beaver influences on the structure and function of river corridor hydrology, geomorphology, biogeochemistry and ecosystems. Earth-Sci Rev [accessed 2003 Dec 17];218:103623. *https://doi.org/10.1016/j.earscirev.2021.103623*

McCann H, Butsic V, Yufang J, Stephens S, Battles J, Cisneros R, Kocher S, Potts MD. 2020. The benefits of headwater forest management. [accessed 2003 Dec 17]. San Francisco (CA): Public Policy Institute of California. 20 p. Available from: *https://www.ppic.org/publication/the-benefits-of-headwater-forest-management/*

McEvoy DJ, Pierce DW, Kalansky JF, Cayan DR, Abatzoglou JT. 2020. Projected changes in reference evapotranspiration in California and Nevada—implications for drought and wildland fire danger. Earth's Future. [accessed 2003 Dec 17];8. *https://doi.org/10.1029/2020EF001736*

Melillo JM, Richmond TC, Yohe GW. 2014. Climate change impacts in the United States. [accessed 2003 Dec 17]. The Third National Climate Assessment. [Washington, DC]: US Global Change Research Program. *https://doi.org/10.7930/J0Z31WJ2*

Pierce C, Vuidon P, Lautz L, Kelleher C, Davis J, 2021. Impact of beaver dam analogues on hydrology in a semi-arid floodplain: Hydrol Processes [accessed 2003 Dec 17];35:e14275. *https://doi.org/10.1002/hyp.14275*

Pierce D, Cayan D, Das T, Maurer E, Miller N, Bao Y, Kanamitsu M, Yoshimura K, Snyder M, Sloan L, Franco G, Tyree M. 2013. The key role of heavy precipitation events in climate model disagreements of future annual precipitation changes in California. J Clim. [accessed 2003 Dec 17];26:5879-5896. *https://doi.org/10.1175/JCLI-D-12-00766.1*

Polade S, Gershunov A, Cayan D, Dettinger M, Pierce D. 2017. Precipitation in a warming world: assessing projected hydro-climate changes in California and other Mediterranean climate regions. Nature Scientific Reports 7:(10783). *https://doi.org/10.1038/s41598-017-11285-y*

Polade SD, Pierce DW, Cayan DR, Gershunov A, Dettinger MD. 2014. The key role of dry days in changing regional climate and precipitation regimes. Nature Scientific Reports. 4:4364. *https://doi.org/10.1038/srep04364*

Pollock MM, Beechie TJ, Wheaton JM, Jordan CE, Bouwes N, Weber N, Volk C. 2014. Using beaver dams to restore incised stream ecosystems: BioScience [accessed 2003 Dec 17];64:279–290. *https://doi.org/10.1093/biosci/biu036*

Ralph FM, James J, Leahigh J, Anderson M, Forbis J, Haynes A, Jasperse J, Lindley S, Talbot C, White M. 2022. Yuba–Feather Forecast Informed Reservoir Operations: preliminary viability assessment. La Jolla (CA): University of California, San Diego. Available from: *https://escholarship.org/uc/item/8x57n58b*

Ralph FM, Hutchinson A, Anderson M, Fairbank T, Forbis J, Haynes A, Sweeten J, Talbot C, Tyler J, White R. 2023. Prado Dam Forecast Informed Reservoir Operations final viability assessment. [accessed 2003 Dec 17]. La Jolla (CA): University of California, San Diego. Available from: *https://escholarship.org/uc/item/8rx4n0vp*

Wuebbles DJ, Fahey DW, Hibbard KA, Dokken DJ, Stewart BC, Maycock TK. 2017. Climate Science Special Report: Fourth National Climate Assessment. Vol. I. [Washington, DC]: US Global Change Research Program. *https://doi.org/10.7930/J0J964J6*

https://doi.org/10.15447/sfews.2023v21iss4art1