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FEATURE

Fighting Fire with Fire: Forecast-Informed Reservoir Operations, Flood, and Drought in California

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IN DECEMBER 2012, CALIFORNIA WAS ALREADY IN ONE of its periodic droughts when a major atmospheric river arrived from over the North Pacific and dropped almost six inches of rain on the Russian River Basin north of San Francisco. Atmospheric rivers are long, narrow, and highly mobile corridors of extreme water-vapor transport that, when they arrive at the West Coast, can drop extreme amounts of rain and snow. Though not all atmospheric rivers cause floods, they dominate California's flood regime—causing about 80% of floods in many of the state's rivers—while also providing 30–50% of its precipitation.

California governor Gavin Newsom holds a news conference in the parched bottom of Lake Mendocino, announcing his drought-emergency proclamation for Mendocino and Sonoma Counties, April 21, 2021. Source: Ken James, California Department of Water Resources.

The December 2012 atmospheric river—like many others historically—filled the Lake Mendocino reservoir of the upper Russian River Basin well above the maximum level allowed in wintertime. Lake Mendocino is designed to help mitigate flood risk, so it is kept partially empty during the winter and spring flood season, like many other reservoirs in this region. For each reservoir, a site-specific water control manual from the U.S. Army Corps of Engineers (USACE) dictates the amount of empty space required to store flood flows should they appear. Because runoff from the December 2012 storm surpassed the mandated flood-management level, the extra water was released from the reservoir as soon as safely possible after the storm, as required by the reservoir's operating rules, restoring empty space in case another flooding storm arrived later.

All was well: the manual had been followed, and the flood risk managed—except that then storms and precipitation stopped showing up in the basin for 13 months. By February 2014, when another major atmospheric river arrived to drop 9.5 inches of rain, water levels in the reservoir had dropped far lower than they had been before the December 2012 storm. The area was then well into a major drought that continued more or less unbroken until winter 2016 or 2017.

What Might Have Been . . .

Water managers and stakeholders throughout the region looked back on those flood-control releases of December 2012 with chagrin, wishing they had known about the dry months and years to come and that they could have retained some of that water to tide the basin over and mitigate some of the major drought impacts.

But rules are rules, and the reservoir's rule curve is clear: When storage in Lake Mendocino rises above 68,400 acre-feet (AF) at any time during November through February, enough water has to be released as soon as safely possible to bring storage back down to that level. This kind of rule is common (though timing and storage limits differ from reservoir to reservoir) for many of the thousands of reservoirs around the country that serve flood-risk management purposes. The rules for most reservoirs were established decades ago, when dams were being constructed and flood-management responsibilities were being distributed to agencies like the USACE. Back then, demands for water were less and it was far safer to develop rules that could accommodate almost any storm or flood in simple, straightforward, and reliable ways based almost entirely on the observed storage level ("water on the ground") than to establish rules that depended on other information—like weather forecasts. The precipitation and streamflow forecasts of decades ago were not reliable enough. They not only would have complicated release decisions but could have resulted in decisions with dire consequences.

In the past two decades, our understanding of the relations between atmospheric rivers, historical floods, and historical droughts on the West Coast, including in the Russian River Basin, has grown tremendously. Simultaneously—perhaps even consequently—the ability of modern weather forecasts to provide warning of the arrival of storms and the inflows they bring to Lake Mendocino has improved markedly. Forecasts are now reliable enough to provide five or more days' notice of the possible arrival of the largest atmospheric rivers. Although landfall locations and intensities can remain uncertain at even shorter lead times, the big storms show themselves as likely somewhere in Northern California several days ahead.

With that information, reservoir managers in December 2012 would have had indications that no major storms were likely to arrive in the forecastable future. By keeping an eye out for the first hints of the next storm to approach and, if need be, releasing part or all of the extra water in the reservoir as soon as that next storm risk was spotted in forecasts, reservoir managers could have safely stored the extra water (beyond what the current rules allow) until after the end of the storm season for use in the long dry summer, fall, and even early winter months to come. In December 2012 this operating strategy was not permitted, but the benefit it could have provided—amounting to more than 12,000 AF of water salvageable from that last atmospheric river (Figure 1A)—became increasingly obvious as the "drought clock" continued to tick away for the many dry months that followed.

Better Forecasts for Better Reservoir Management

One consequence of that episode was that representatives from eight local, state, and federal agencies and institutions gathered in early 2014 to begin

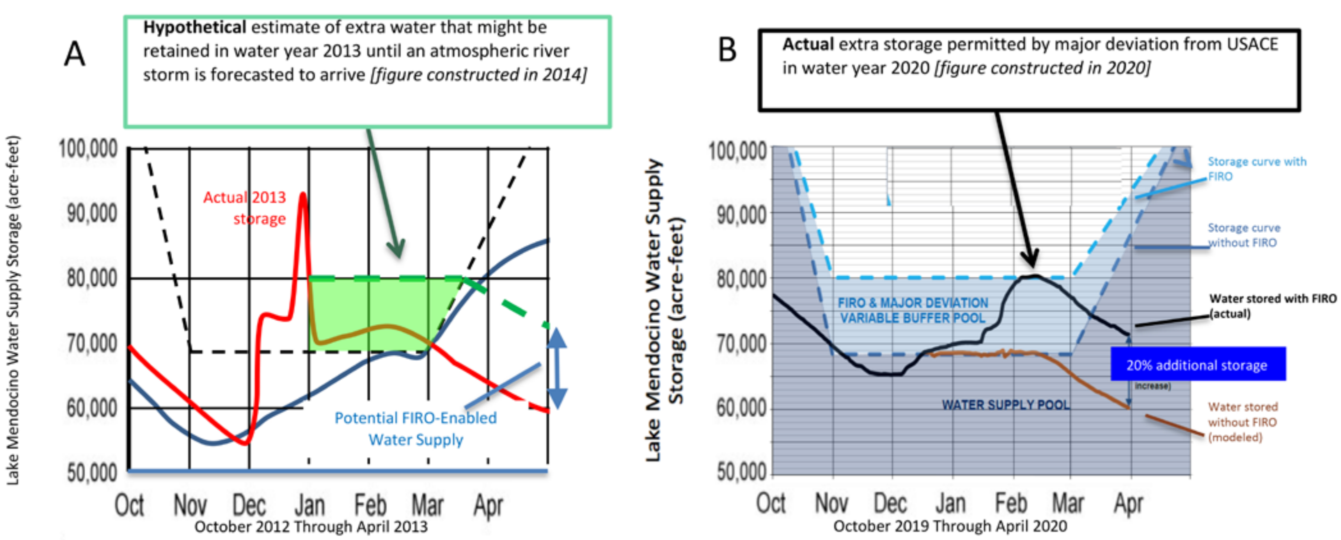

Figure 1. The FIRO concept at Lake Mendocino, (A) as envisioned for water year 2013 and (B) as realized in water year 2020. A: Black dashed line is the existing rule curve showing how much water can be stored according to the water control manual. The blue curve is the 10-year averaged storage levels in the lake. The red curve is actual storage levels in water year 2013. The green shading and dashed line are storage that FIRO might have made possible. B: Blue dashed curves are the existing rule curve and operating leeway allowed by the current "major deviation" permitted by USACE. The black curve is actual reservoir storage in water year 2020, and the red curve is modeled storage under the existing rule curve.

to determine whether modern forecasts and decision tools can be used to inform reservoir operations in ways that would allow more water to be saved, safely, in Lake Mendocino. Are modern forecasts reliable enough to ensure that reservoir operations based on them would be safe—that is, would pose no increased flood risks downstream of the reservoir? Would forecast-informed reservoir operations (FIRO) as safe as this result in more reliable water supplies? Or are those decades-old rules still the only safe approach?

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The multidisciplinary team that came together to evaluate the risks and benefits of FIRO at Lake Mendocino included reservoir operators, managers, and researchers from the USACE; water-resource managers from Sonoma Water; atmospheric and hydrologic scientists from the Scripps Institution of Oceanography; forecasters from the National Weather Service's California Nevada River Forecast Center; fisheries experts, atmospheric scientists, and other researchers from the National Oceanographic and Atmospheric Administration; and interested decision makers, engineers, biologists, and scientists from other agencies. Using a variety of methods, the accuracy of current forecasts was evaluated and compared with the levels of accuracy needed to successfully and safely improve reservoir yields from Lake Mendocino. Flood risks and reservoir operations were modeled and tested against a variety of historical storms (and real-world forecasts) and hypothetical more extreme storms. And new decision supports were developed and tested.

The outcome of these studies was a recently released, thoroughly reviewed and tested, multiagency Final Viability Assessment that concludes that FIRO can not only reduce downstream flood risk and improve environmental flows but also supply about 20% more water than strict adherence to the existing water control manual. For the past several years, this new way of operating the reservoir has actually been implemented under temporary "major deviation" permits from the USACE, which is now developing a new water control manual that reflects the findings on FIRO.

As we write this, California is deep in yet another drought. In 2021 only a single moderate-sized atmospheric river arrived to provide precipitation to the state, and in 2020 only two arrived. Because of the FIRO-based major deviation at Lake Mendocino, however, the reservoir entered summer 2020 with 20% more water in storage than under historical rules (Figure 1B). Thus, FIRO is already proving its value in the real world.

A consensus of climate-change projections for California is that the state will face more and deeper droughts in coming decades, interspersed with more and wetter atmospheric rivers. Our hope is that continued investments in improving forecast accuracies and the kinds of modern forecast-informed operations that are already proving beneficial at Lake Mendocino in today's climate can help accommodate these changes by increasing the reliability of water supplies and reducing flood risks, without the need for major new infrastructure investments.

FIRO will not be a panacea everywhere. But where modern forecast accuracy and operational constraints come together to allow it to safely improve water supply outcomes, this is a strategy (along with others like Flood-MAR) that can provide new ways to fight the "fires" of increasing drought by capturing the "fires" of increased floodwaters. In the end, we need to revisit and improve on our increasingly outdated operational rules if we are going to accommodate the new water resources challenges of this rapidly changing world. ■

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