SAN FRANCISCO ESTUARY & WATERSHED SCIENCE
Sponsored by the Delta Science Program and the UC Davis John Muir Institute of the Environment

Storage in California's Reservoirs and Snowpack in This Time of Drought

Michael D. Dettinger* and Michael L. Anderson[1]

Volume 13, Issue 2 | June 2015

* Corresponding author: *mddettin@usgs.gov*; U.S. Geological Survey, La Jolla, CA 92093 USA and Scripps Institution of Oceanography, La Jolla, CA 92093 USA

1 Division of Flood Management, California Dept. of Water Resources, Sacramento, CA 95814 USA

doi: *http://dx.doi.org/10.15447/sfews.2015v13iss2art1*

INTRODUCTION

The San Francisco Bay and Sacramento–San Joaquin Delta (Delta) are the recipients of inflows from a watershed that spans much of California and that has ties to nearly the entire state. Historically, California has buffered its water supplies and flood risks both within—and beyond—the Delta's catchment by developing many reservoirs, large and small, high and low. Most of these reservoirs carry water from wet winter seasons—when water demands are low and flood risks are high—to dry, warm seasons (and years) when demands are high and little precipitation falls. Many reservoirs are also used to catch and delay (or spread in time) flood flows that otherwise might cause damage to communities and floodplains. This essay describes the status of surface-water and snowpack storage conditions in California in spring 2015, providing context for better understanding where the state's water stores stand as we enter summer 2015.

RESERVOIR STORAGE

About a dozen major reservoirs (listed in Figure 1) operated by state, local, or federal agencies, hold about half of the water stored in California's reservoirs, on average. Hundreds of other, mostly smaller reservoirs are scattered around the state and together store amounts of water roughly equal (on average) to the storage in the dozen major reservoirs. In early spring snowpack in the state's mountains also contains about 70% as much water, on average, as the long-term average combination of the major and "other" reservoirs. Figure 1 shows the history of reservoir storage[1] in the dozen major reservoirs and in another 148 reservoirs across California (including two in the Klamath River basin just across the border in Oregon) during the past 45 years. As expected, in dry periods such as 1976–77, the late 1980s to early 1990s, the end of the 2000s and, again, during the present drought (2012–2015), the amount of water stored in California's reservoirs declines and, in wet years such as 1978, 1983, 1998, 2005–2006 and 2011, storage in reservoirs recovers.

The dozen major surface reservoirs listed in Figure 1 are used aggressively to ameliorate droughts and floods. As a consequence, their storage fluctuates more from winters to summers, and from year to year, than does the total of storage in the other reservoirs. For example, between April 2011 and April 2015, total storage in the major reservoirs declined by 50% while storage in the other reservoirs declined by 38%. Indeed, over the long term illustrated in Figure 1, the variance of monthly storage in the

1 Monthly reservoir-storage, precipitation, and statewide April 1 snow water content estimates were obtained from *http://www.cdec.water.ca.gov*, an open-access California Department of Water Resources data archive.

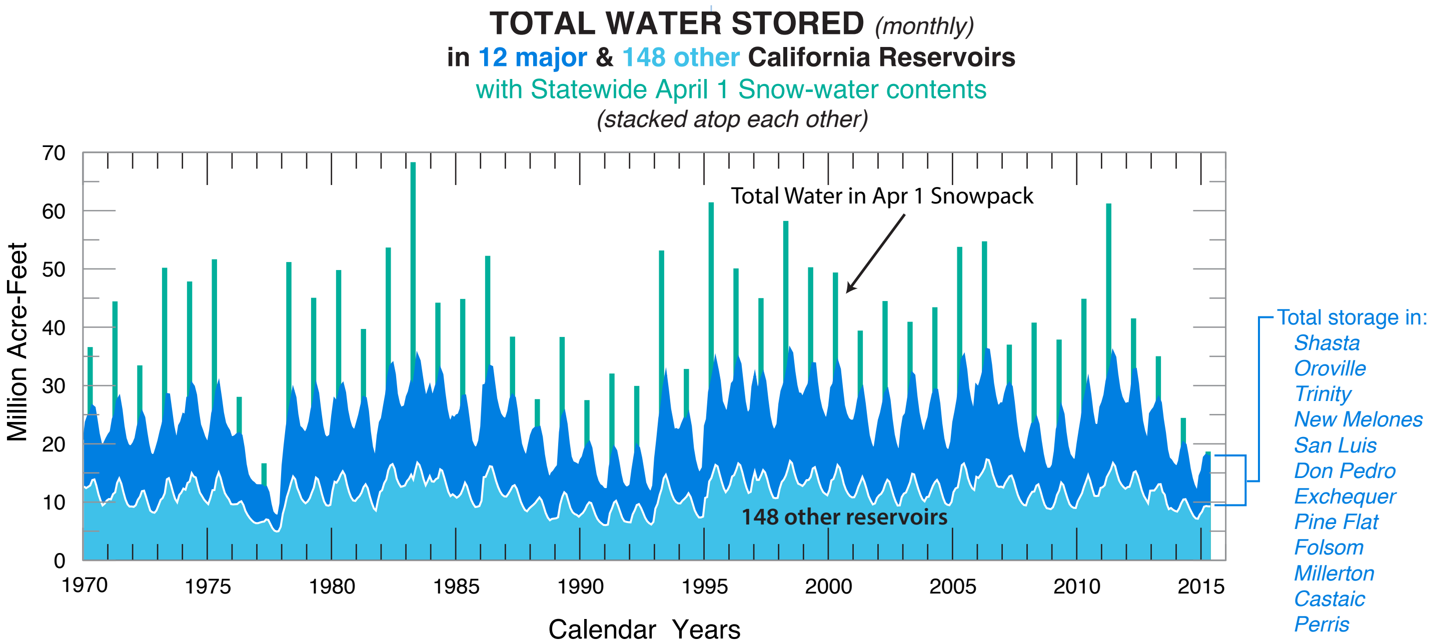

Figure 1 Monthly totals of water stored in (dark blue) 12 major reservoirs and (light blue) 148 other, mostly smaller reservoirs, stacked on top of each other, and (green bars) estimated statewide-total of water stored in April 1 snowpacks each year, January 1970 through April 2015

major reservoirs is 166% of the variance of storage in the other 148 reservoirs. The major reservoirs are vital assets during droughts and need to be carefully monitored. Nonetheless, in isolation, they tend to overstate the depth of "storage droughts" over long periods of time.

RECENT STATUS OF RESERVOIRS

Winter 2015 was not the driest on record, with 74% of normal precipitation falling in northern California.[1] However, because the winter was the warmest on record, little snowpack formed, and most runoff that was going to happen arrived during the winter. As a result, storage in over half of the state's reservoirs actually increased somewhat in recent months. To illustrate this, Figure 2 shows statewide reservoir conditions during April 2015 (2A), the changes between February and April 2015 (2B), and the 30-year normal changes between the two months (2C). The number of reservoirs with well below normal storage increased from February to April at the expense of the number with storage near or well above normal, and increases that occurred were generally small. Nonetheless, storage in more reservoirs increased rather than declined. In a normal year, however, larger changes are expected (richer colors, Figure 2C) and storage in nine times as many reservoirs would have increased. Overall reservoir replenishment in winter 2015 was only about 9% of normal. As a result of the rains that fell in northern California and careful management, California's total reservoir storage managed to hold its own, but just barely—and not enough to put us into good standing for the months to come. Although in aggregate, reservoir storage remained more or less stable through the late winter, some reservoirs fared far worse than the average (e.g., storage in Pine Flat Reservoir on the Kings River and Isabella Reservoir on the Merced—to name just two—received remarkably low replenishments this winter).

SNOWPACK STORAGE

The vertical green bars in Figure 1 are estimates of total water stored in April 1 snowpacks. These estimates are based on a combination of (a) the yearly estimates[1] of the "statewide snow water content as

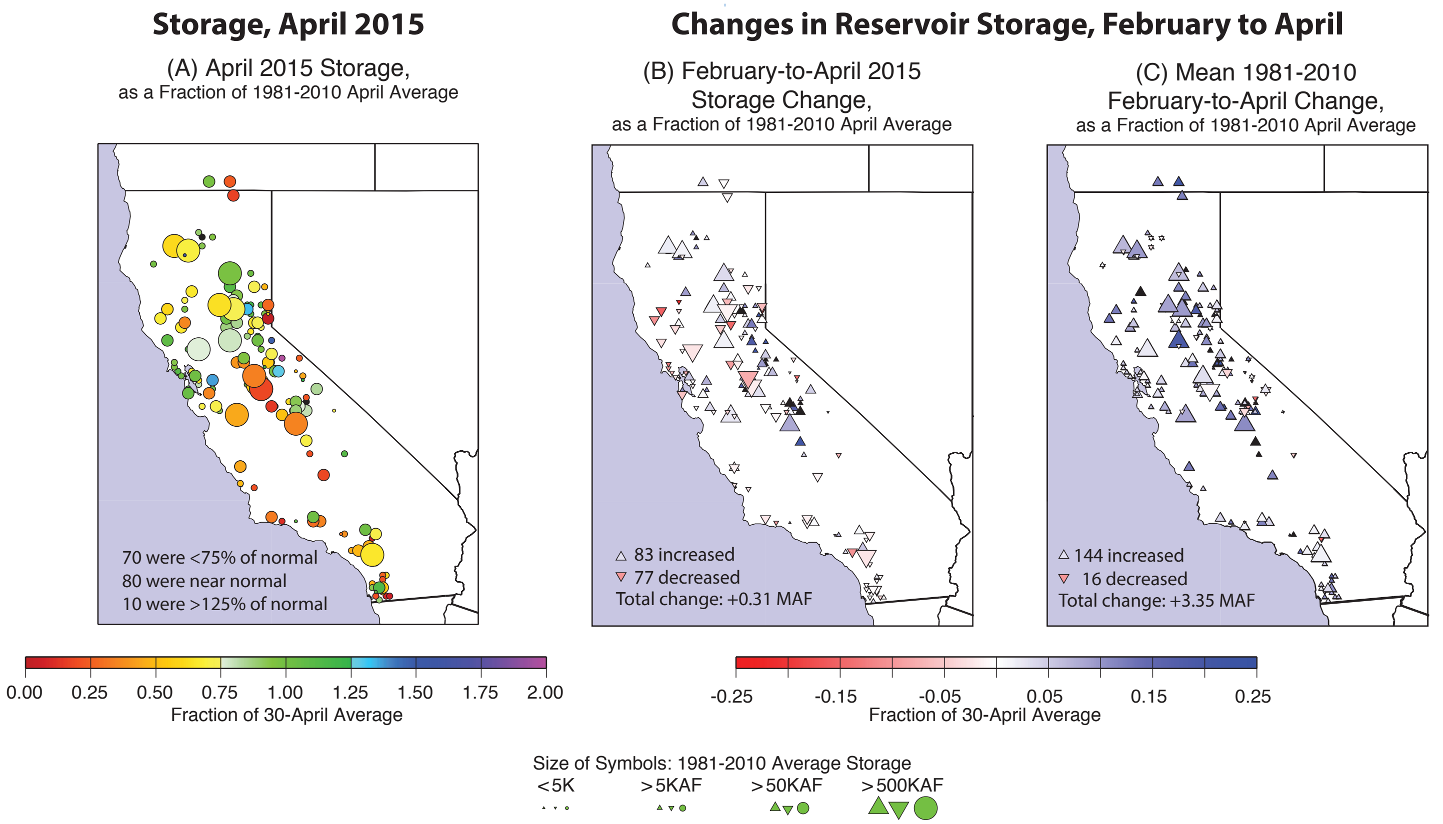

Figure 2 Reservoir storage in (**A**) April 2015, as fractions of long-term normal April values, and changes in storage from February to April in (**B**) 2015 and (**C**) under long-term normal conditions, as fractions of long-term normal April storage volumes

a percentage of average April 1 snows" that the California Department of Water Resources makes, and (b) a long-term average April snow water content for California of 17 million acre-feet (MAF; 21 km^3) simulated by the Variable Infiltration Capacity (VIC) model (Liang et al. 1994), statewide. The long-term average sum of the major—and other—reservoir storages in Figure 1 is 23.5 MAF, so that California's snowpacks have historically provided an average 71% of additional seasonal storage.

By April 2015, total reservoir storage amounted to 17.8 MAF, very close to the long-term average simulated value of April snow water contents in the state—or about 75% of the long-term average total-reservoir storage in Figure 1. However, the April 2015 estimate of snow-water content for the state was only 5% of normal, as a result of record-breaking warm winter conditions and meager precipitation totals.

The current challenge to statewide water managers is less the lack of water in the reservoirs and much more the lack of water in snowpacks that normally would be expected to melt soon and replenish our reservoirs. However, reservoirs like Exchequer on the Merced River and Pine Flat on the Kings are facing the double challenge of very low winter inflows resulting in low April storage levels, coupled with lack of snowpack to replenish in the remainder of this year.

A simple regression analysis (not shown here) of the relations between the April snowpack totals (Figure 1) and subsequent declines in reservoir storage in the remainder of the year (measured from Figure 1) allow estimates of how much California's reservoirs are likely—all other things being equal—to decline in this year of little or no snowpack. Without a snowpack, on average, total-storage drawdown might be

http://dx.doi.org/10.15447/sfews.2015v13iss2art1

Figure 3 Thomas A. Edison Lake in the Upper San Joaquin River basin on March 28, 2015, when this 125,000 acre-foot reservoir's storage was 18% of normal for that time of year, and the basin's snowpack was 8% of normal. *Photo credit: M. Dettinger.*

expected to reach 12 MAF from the April value of 17.8 MAF. By April 2015, storage in the major reservoirs totaled 8.6 MAF. With essentially no more snowmelt likely to replenish the reservoirs, drawdown of the major reservoirs could reach 7 MAF, on historical average and barring extraordinary measures to conserve the water already in the reservoirs. However, in past dry years (2014 and especially 1977), water users and managers responded proactively, and were able to significantly reduce drawdowns that otherwise would have been expected.

SUMMARY

Storage in the dozen "major" reservoirs that are generally monitored averages slightly more than the storage in another 148 other reservoirs considered here, but fluctuates from year to year, with up to 161% variance from storage in the other reservoirs. Thus, drought conditions are accentuated (appear more severe) if only the major reservoirs are monitored or considered.

Expanding consideration to cover this broader-than-usual sampling of reservoir storage in California, we find that the much smaller-than-normal wintertime storage increases during 2015 present difficulties for meeting water demands later this year, but far more challenging is this spring's lack of snowpack, which leaves us anticipating very little snowmelt to meet demands and to replenish the reservoirs. All other things being equal, one would predict, from a starting point of about 17.8 MAF, reservoir drawdowns would be about 12 MAF later this year, with the large majority coming from the major reservoirs. However, in the poorest snowpack years (e.g., 1977 and 2014), drawdowns have not been as large as the long-term relationships suggest, so there is room for some optimism. Thus, while California's reservoirs overall are unlikely to empty completely in this continuing drought year, reservoir storage may decline to levels that have not been witnessed in the past 45 years, and the major reservoirs—some of which are the principal controls on Delta inflows—will empty far more thoroughly than the other reservoirs, in aggregate, if history is our guide.

REFERENCES

Liang X, Lettenmaier DP, Wood EP, Burges SJ. 1994. A simple hydrologically based model of land surface water and energy fluxes for general circulation models. J Geophys Res 99(D7):14415–14428. doi: *http://dx.doi.org/ 10.1029/94JD00483*

http://dx.doi.org/10.15447/sfews.2015v13iss2art1