Summary of CCRS White Paper 4

The Future Hydrology of the Colorado River Basin

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Seeing the Future

Long-range planning of the water supply provided by the Colorado River requires realistic assessments of the impact of a continuation of the current drought that began in 2000, the impact of potentially extreme future droughts, and the long-term and progressive decline in watershed runoff that is caused by a warming climate. Water-supply managers want to know the maximum plausible stresses to water users so that plans for conservation, reservoir operations, and/or construction of new infrastructure can be properly developed. River managers want to know the implications of various water-supply plans on the flow-regime and water-quality characteristics of the Colorado River and its headwater branches in order to develop natural resource management plans that maintain desired attributes of river ecosystems. Although it is relatively easy to qualitatively describe scenarios of drought or water abundance, it is much harder to quantitatively estimate likely future conditions. In the white paper, we developed methods to make such quantitative estimates, thereby providing an approximate answer to the question, "***How dry might future conditions in the Colorado River watershed become?***" It is difficult to assign a probability to this assessment, and our analysis is guided by the principle that ***what has happened in the past might happen again in the future***.

The analysis is guided by the principle: if it has happened in the past, it might happen again in the future.

We evaluated the record of natural runoff at Lees Ferry based on analysis of historic observations and tree-ring streamflow reconstructions. The Lees Ferry record is widely used by water-supply managers to evaluate the supply of water available for allocation among the states of the Colorado River basin, as well as by Mexico. To evaluate the severity of sustained droughts, we advanced a new and powerful analysis methodology based on calculating sequence-average and cumulative depletions relative to the natural flow mean. These analyses show that the current millennium drought that started in 2000 has an average flow far less than the natural flow record starting in 1906 available from the U.S. Bureau of Reclamation. However, ***when viewed from the perspective of past flows reconstructed from tree-rings, or future flows projected from climate models, significantly more severe droughts are not only plausible, but increasingly likely, recognizing that hotter and drier conditions are making matters worse.***

Simulating the Worst

We identified the magnitude and duration of the most severe droughts of the past 600 years. Three past droughts stand out in the record of prior flows. We use the term ***millennium drought*** to refer to the period between 2000 and 2018—***mean flow of 12.44 million acre feet/year (maf/yr) for 19 years; 2.3 maf/yr less than the long term mean of 14.76 maf/yr*** computed from the 1906-2018 natural flow record. The ***mid-20th century drought*** was the period between 1953 and 1977—***mean flow of 12.89 maf/yr for 25 years***; ***1.9 maf/yr less than the long term mean***. Both of these are plausible scenarios of future droughts, because they have occurred in the recent past and indeed may be continuing today. We use the term ***paleo tree-ring drought*** to refer to the period between 1576 and 1600 that is based on tree ring estimates of streamflow—***mean flow of 11.76 maf/yr for 25 years; 3 maf/yr less than the long term mean***.

We implemented an analytical scheme that assumed that years of low runoff that occurred in the worst of past

What you'll find in the paper:

- Details of three drought scenarios that would severely test the operational rules, and planning and management strategies of the Colorado River system.
- An example of the stresses that a severe sustained drought would place on the Colorado River possibly lowering pool elevations of Lake Powell to levels less than needed to produce hydropower.
- An examination of whether the declining streamflow trend in the 20th century is due to the anomalous wet period from 1906-1929.
- Separate sidebar analyses on historical flow in the Colorado River, natural flow losses below Hoover Dam, the estimation of streamflow in the absence of human influence, details of the unusual Early 20th century pluvial period from 1906-1929, and the effects of climate related forest change on runoff.

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droughts might occur again in the future but that the sequence in which these years of low runoff occur in the future might differ from what occurred in the past. This method simulates possible future droughts by developing sequences of low runoff years randomly selected from the records of the three severe past droughts described above. Each grouping of randomly-assigned sequences of low-flow years drawn from one of these past droughts is referred to as a ***scenario***. Multiple (100) sequences were simulated for each scenario. These scenarios would severely test the operational rules, and planning and management strategies of the Colorado River system. Each scenario, and each sequence within each scenario, is based on past flows that actually occurred in the 20th or 21st century or has been estimated from tree-ring hydrology. The random ordering of years of low flow is a justifiable approach to estimating possible conditions in the future, because it has been shown that year-to-year correlation of flows in the Colorado basin is small. Climate change studies show that, with warming, runoff will decline in the future. We show that the random sequences we have produced for each scenario are within the range in severity of the droughts derived from climate projections. In fact, the most severe of future climate projections produced from general circulation models (GCM) that were selected by the best reproduction of historic drought severity, suggest more severe future droughts than those of our study. Thus, future warming of Earth's climate might make matters even worse than we estimate here.

The work in this white paper is novel, because we combined analysis of the most recent Lees Ferry natural flow estimates provided by tree-ring hydrology studies with the drought-scenario-based resampling methodology outlined above. ***Our results demonstrate that planning in which the 1988-2018 period containing the current drought is used as a stress test might not consider drought scenarios that are sufficiently extreme. The future might be far drier than managers currently anticipate.*** An additional aspect of our research is that ***we developed and implemented a scheme for incorporation of our estimates of future drought at Lees Ferry into the Colorado River Simulation System (CRSS).*** This effort required development of a disaggregation method that estimates future drought conditions at every input node of CRSS. [These data are available](#) as supplementary data to this white paper (Salehabadi and Tarboton, 2020). Our goal is to provide a rigorous quantitatively derived set of drought scenario inputs that can be used by any stakeholder proficient in CRSS, or any other model of the Colorado system, who wishes to analyze current risks or alternative management paradigms that might be useful in confronting severe sustained long-term drought.

We also provided one example of the stresses that a severe sustained drought would place on the Colorado River system by using the CRSS model and our quantitative estimates of future droughts to evaluate the frequency of Lake Powell elevations declining below a critical threshold if "business as usual" water management were pursued during a severe drought. We ran the April 2020 version of CRSS initialized with the projected January 1, 2021 reservoir conditions, the current interpretation of the Law of the River within CRSS, and the future drought scenarios estimated in this study. We compared our results with predicted conditions based on the hydrology represented using the Index Sequential Method derived from the natural flow estimates calculated by Reclamation. The scenarios we developed indicate that there would be long periods when Lake Powell pool elevations would fall below that which is required to produce hydropower. Thus, new strategies and plans will be necessary to confront the challenge of severe future droughts.

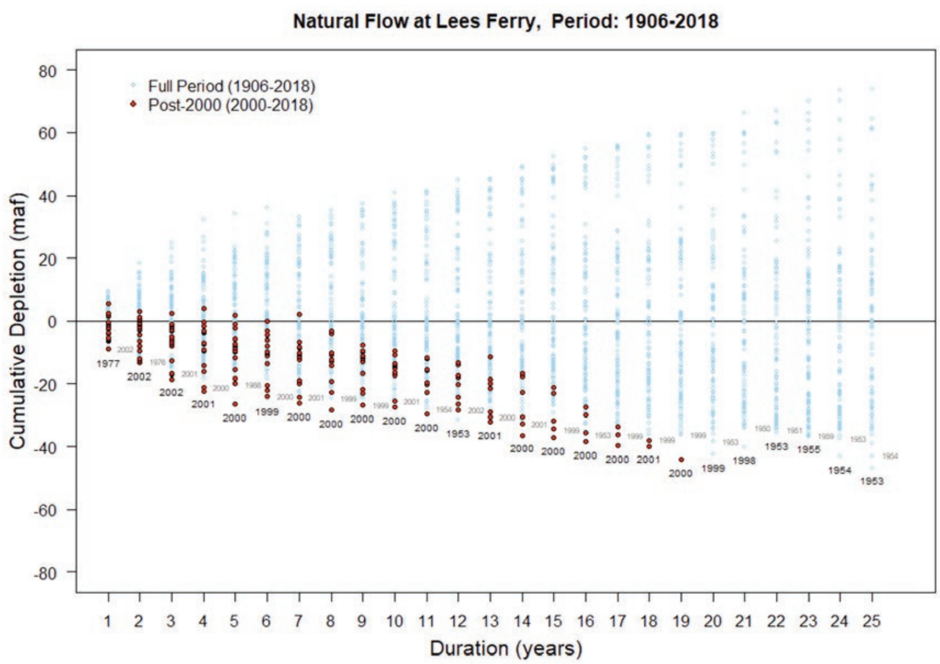

Fig. 1. Cumulative Depletion plot of the natural flow of the Colorado River at Lees Ferry 1906-2018. Each dot represents water year annual flow minus long term mean summed over the duration. There is a dot for each sequence of the given duration (including overlaps) within the record. Negative numbers in the lower part of the graph depict the amount by which the sum of water year flow was less than the mean, i.e. a depletion. Dot labels give the start year of the largest (black number) and second largest (gray number) depletion. The spread of the dots for each duration characterizes how cumulative depletion may vary for different durations. It is notable that for the 19 year period starting in 2000, a depletion of close to 40 maf relative to the mean is accumulated. It is also notable that, for the majority of durations, the 2000-2018 period contributes the largest cumulative loss, reinforcing the severity of the current drought.

Find Out More:

- Read the complete white paper : https://qcnr.usu.edu/coloradoriver/files/WhitePaper4.pdf
- Data Citation: Salehabadi, H., D. Tarboton (2020). Data Collection to Supplement the Future Hydrology of the Colorado River Basin Study, HydroShare, http://www.hydroshare.org/resource/6d351874f16947609eab585a81c3c60d