Colorado River Basin Climate and Hydrology: State of the Science

A synthesis report to support water planning and management

WESTERN WATER ASSESSMENT
A NOAA RISA TEAM

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CIRES

Background

The Colorado River Basin is a vital source of water, eco-system services, hydropower, recreation, and other amenities for the seven basin states (Colorado, Wyoming, Utah, New Mexico, Arizona, Nevada, and California), at least 22 federally recognized tribes, and Mexico.

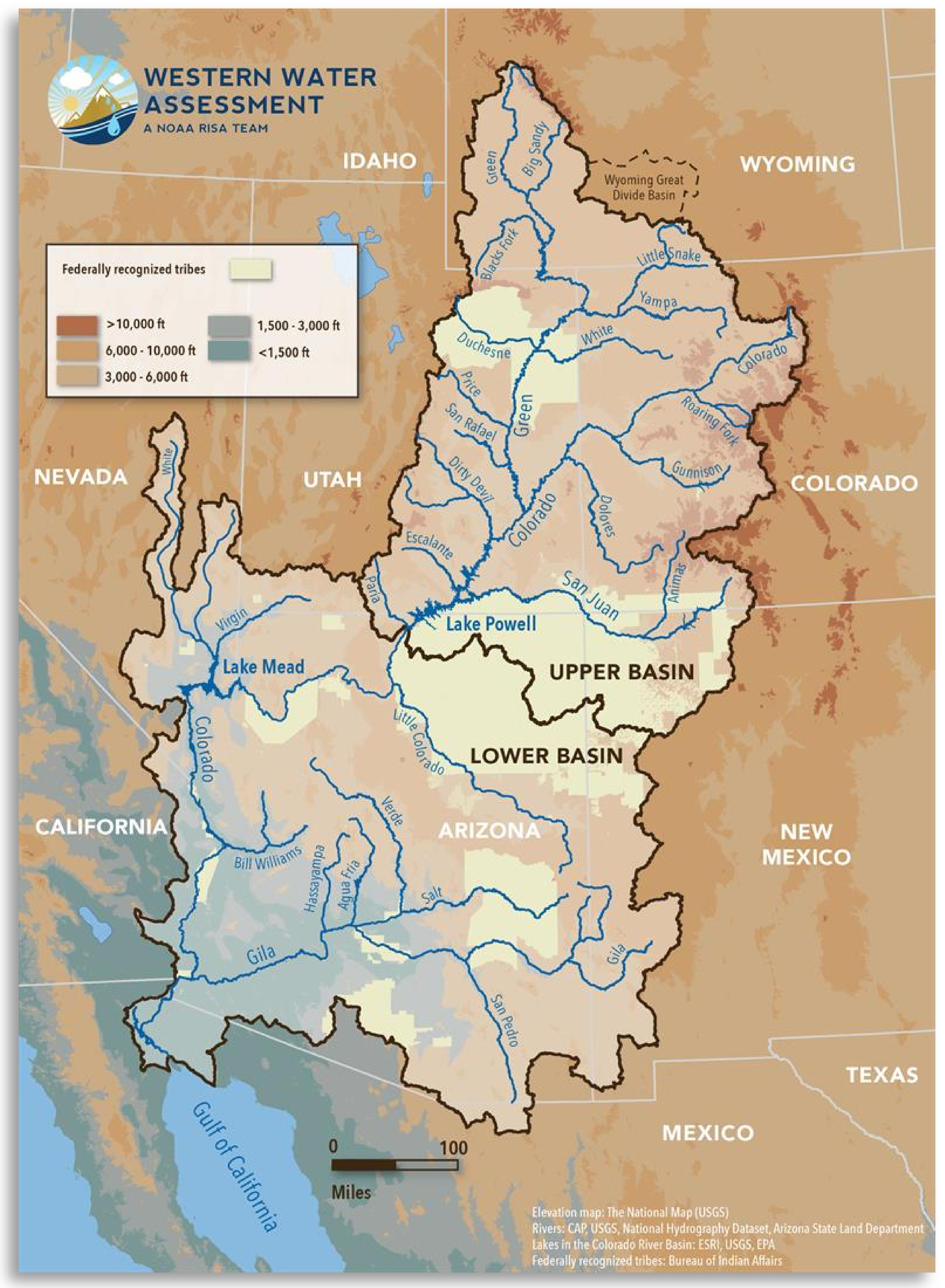

Figure 1. Colorado River Basin

To inform their operational decision-making and long-range planning, water managers in the Colorado River Basin routinely produce and consult forecasts of reservoir storage and other system conditions at short-term and mid-term timescales, and also system projections for the long-term. Further sharpening these outlooks, and reducing the uncertainties where possible, can help in better managing the basin's increasingly stressed water supply.

Figure 2. Report sponsors

In 2018, the Colorado River Climate and Hydrology Work Group, composed of state water agencies and municipal and regional water entities, and the Bureau of Reclamation, approached Western Water Assessment (WWA) to develop a science synthesis report for the basin. In addition to funding and guidance from these sponsors, substantial technical assistance was provided by the NOAA Colorado River Basin Forecast Center (CBRFC) and the USGS.

Objectives and scope

By synthesizing the state of the science in the Colorado River Basin regarding climate and hydrology, the report seeks to establish a broadly shared understanding that can guide the strategic integration of new research into practice. The specific objectives were:

- Synthesize recent findings that can inform forecasts and projections of hydroclimate and system conditions.
- Convey the knowledge gaps and uncertainties associated with each area of the science and technical practice.
- Prompt research ideas and inform research priorities by describing opportunities for closing knowledge gaps.
- Inform the scientific community about Reclamation models, how they support operations and planning, and related research needs.
- Provide a broadly accepted foundation of scientific and technical information to support the review and potential renegotiation of the Interim Guidelines.

The report starts with our current understanding of the patterns, processes, and trends in the basin, then moves to the primary data and models that are based on observations of climate and hydrology, which then feed into short-term and mid-term forecasting tools for weather, climate, and streamflow, as well as the development of hydrologic traces for long-term planning.

The report does not evaluate current basin operations or policy. It identifies opportunities for research and improvements, but without providing explicit recommendations. Its primary focus is water supply; water use, in terms of evapotranspiration, is addressed briefly, but water quality, fisheries, ecosystem management, and sedimentation fall outside the report's boundaries.

Key points

To make the rich content of the 500-page report more tractable, the most relevant findings of each chapter were summarized in key points by chapter.

Current Understanding of Basin Climate & Hydrology

- The position and frequency of cold-season storm tracks is the main driver of inter-annual variability in basin runoff.
- 85% of annual runoff comes from the 15% of the basin's area, in the mountain headwaters.
- There has been a substantial warming trend (2°F) over the past 40 years.
- Decreases in spring snowpack and shifts to earlier runoff timing have occurred, in part due to warming.
- Multiple studies indicate that runoff efficiency has decreased due to warming, in part leading to below-average runoff since 2000.

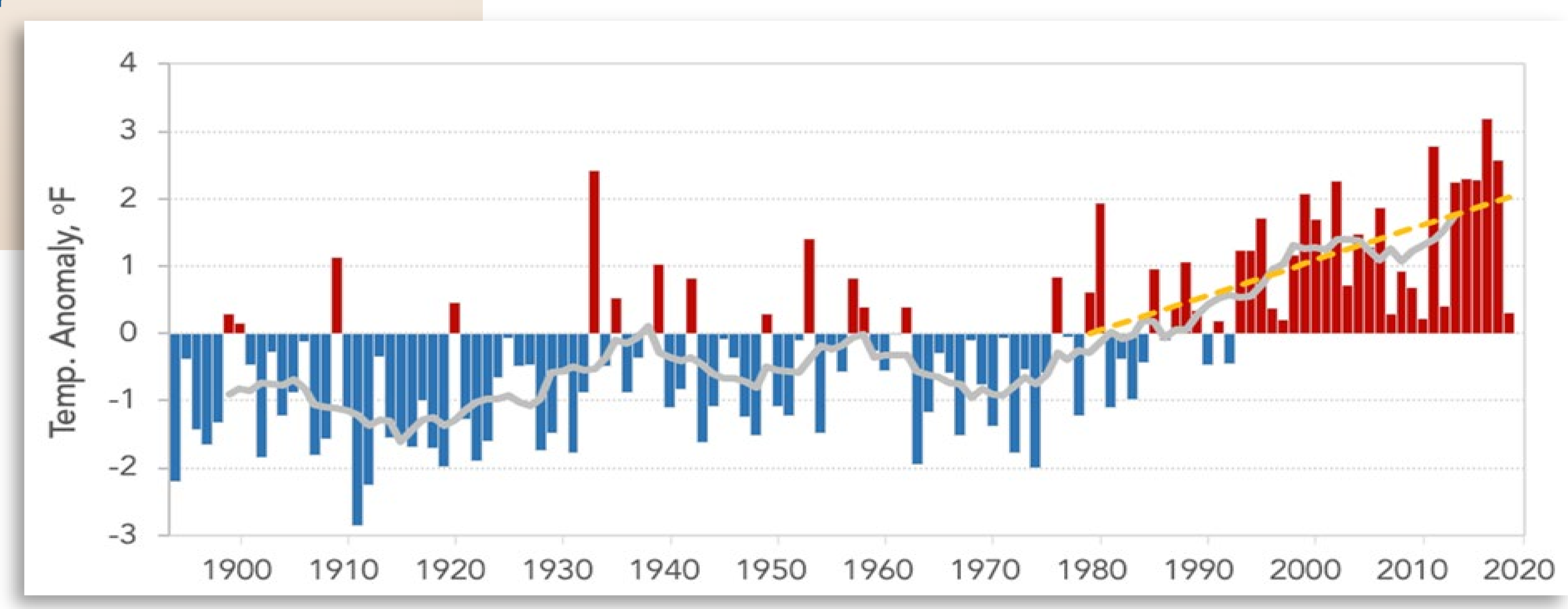

Figure 3. Annually averaged temperature for the Colorado River Basin, 1895–2019, shown as departures from a 1970–1999 average. (Data: NOAA NCEI)

Key points

Observations—Weather, Climate and Hydrology

- Observation station coverage over the basin varies in both space and time, and high-elevation mountain areas, which produce most of the runoff, have generally low station densities, especially before 1980.
- The various gridded climate data products use similar sets of observations as inputs, but they can have important differences between them for some locations and time periods.
- In situ networks like SNOTEL are being increasingly augmented by modeled and remotely sensed spatial data but remain essential to monitoring and model calibration.
- Realizing the full value of spatial hydrologic data will ultimately require streamflow-forecasting and system-modeling frameworks that are explicitly designed to use those data as inputs.

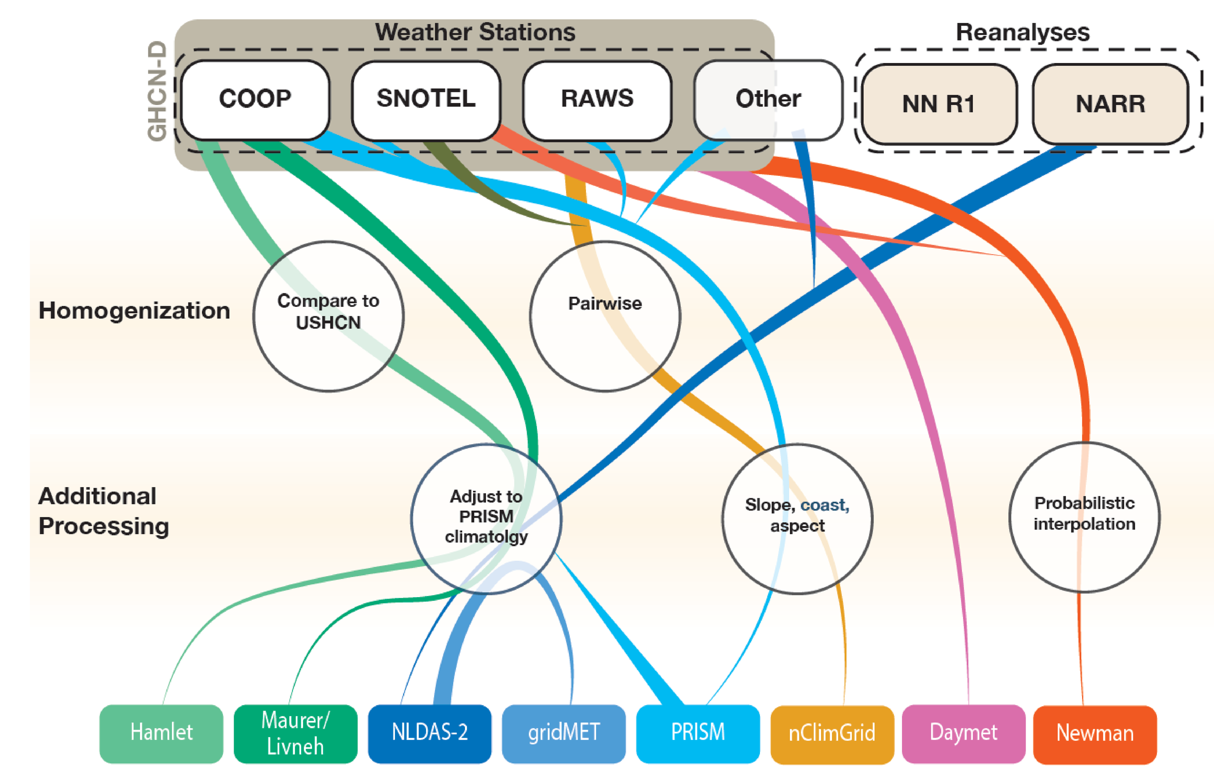

Figure 4. Flow diagram of the data sources and processes used to produce high-resolution gridded precipitation products.

Weather and Climate Forecasting

- Uncertainty about upcoming weather and climate conditions translates into a major source of uncertainty in seasonal streamflow forecasts.
- Weather forecasts out to 7-10 days have relatively high skill and are progressively improving; they are incorporated into the CBRFC's streamflow forecasts.
- Sub-seasonal and seasonal climate forecasts (2 weeks to 1 year) have much lower skill, especially in the Upper Basin.

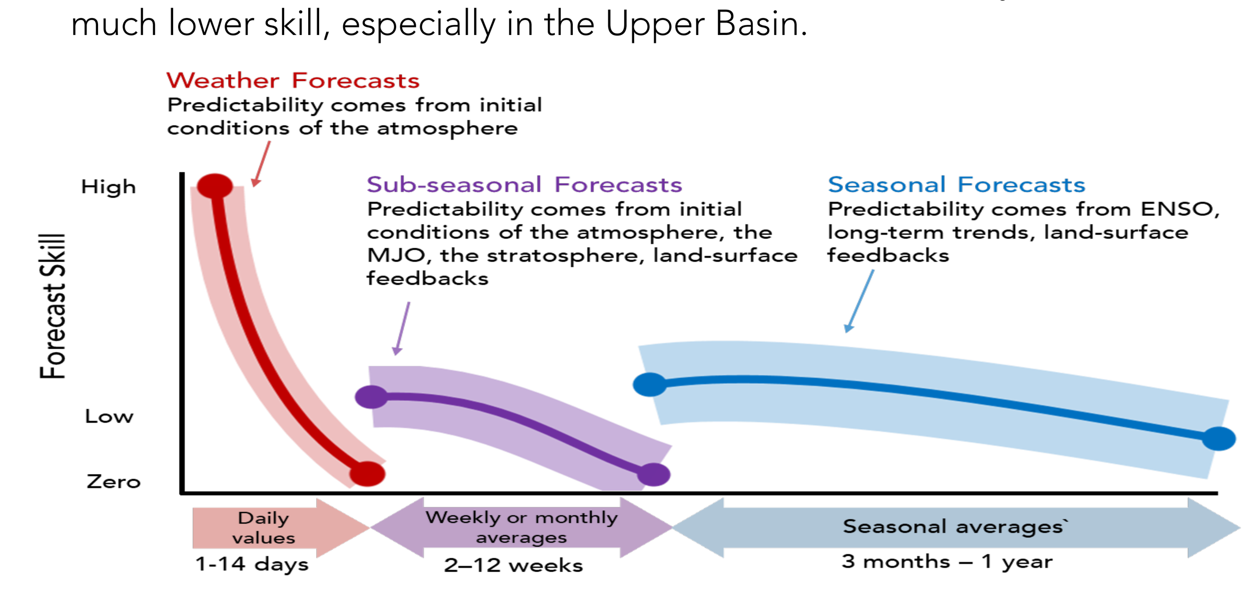

Figure 5. Typical forecast skill vs. time horizon for three main types of weather and climate forecasts. (Source: adapted from a figure by Elisabeth Gawthrop and Tony Barnston, International Research Institute for Climate and Society).

Streamflow Forecasting

- Streamflow predictability at seasonal timescales in the basin arises primarily from the initial watershed moisture conditions, i.e., snowpack and soil moisture.
- The CBRFC and NRCS forecasts capitalize on this predictability, with relatively high skill for forecasts issued in late winter and spring for the spring-summer runoff season.
- Better quantification of initial watershed moisture conditions, and improving climate forecasting are the main pathways to improving seasonal streamflow forecasts.

Key points

Historical Hydrology

- The index sequential method to generate streamflow traces from the historical record has both advantages and limitations because it does not deviate from the observed streamflow record.
- Stochastic methods produce ensembles that maintain many characteristics of the historical record while offering novel ranges, durations, and frequencies of flows.
- Recent research has focused on non-parametric stochastic methods and hybrid methods that blend historical streamflows with tree-ring paleohydrology or climate change-informed hydrology.

Paleohydrology

- Tree-ring reconstructions of basin streamflows extend the observed natural flow record up to 1200 years and show a broader range of hydrologic variability and extremes, including multi-decadal mega-droughts.
- The early 20th century high-flow years (1905–1930) may have been the wettest period in 500–1000 years.
- Methodological choices in the handling of the tree-ring data can influence the reconstructed flow values and metrics, such as the duration of droughts.

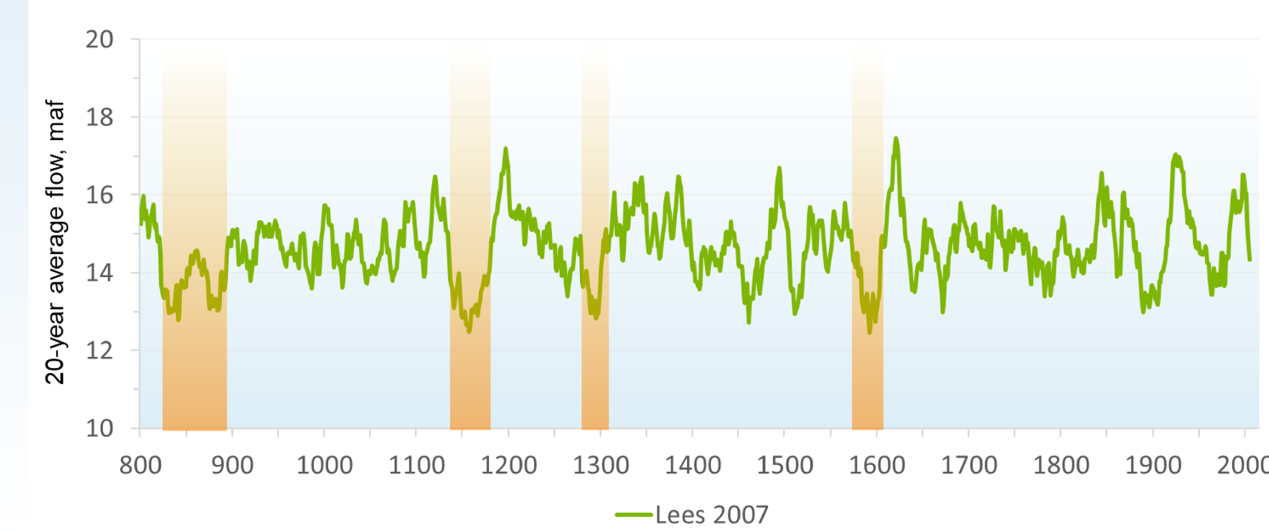

Figure 6. Reconstructed annual flows, with a 20-year running average, for the Colorado River at Lees Ferry from Meko et al. (2007). Four "megadroughts," more severe and persistent than any post-1900 drought, are highlighted in yellow.

Climate Change-informed Hydrology

- Most climate change planning approaches begin with global climate models (GCMs); the final output is sensitive to multiple processing choices.
- Downscaling methods make GCM output more usable for finer-scale hydrologic modeling, but are not necessarily more accurate than the underlying GCM output.
- Due mainly to the pervasive effects of continued future warming on the water cycle, decreased basin annual runoff volumes are likely.

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