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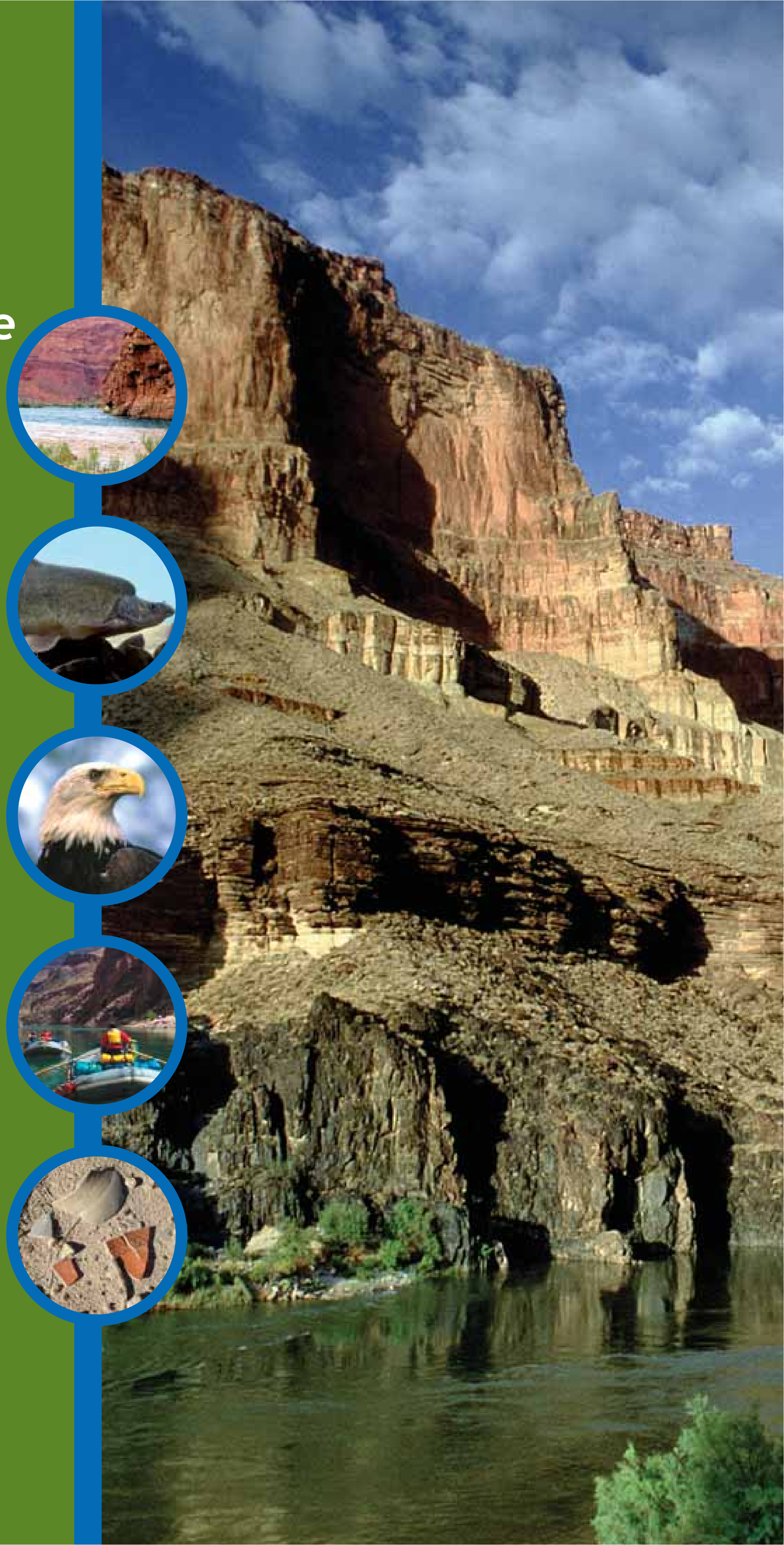
The State of the Colorado River Ecosystem in Grand Canyon

A Report of the Grand Canyon Monitoring and Research Center 1991–2004



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U.S. Geological Survey

Chapter 3

Climatic Fluctuations, Drought, and Flow in the Colorado River

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Introduction

Climate is the cumulative pattern of daily atmospheric conditions in a particular geographic area, and weather is the daily and seasonal expression of these conditions. Climate varies over periods of years, decades, or centuries, altering weather conditions in a region, particularly precipitation amounts and temperatures. In the arid and semiarid Southwest, climatic fluctuations affect many hydrologic characteristics of watersheds, including the quantity of base flow, the occurrence of large floods, and the timing of snowmelt runoff (Dettinger and Cayan, 1995; Cayan and others, 1999; Stewart and others, 2004, 2005; McCabe and Clark, in press).

Reservoirs in the Western United States, particularly those in the Colorado River Basin, were built to reduce, if not eliminate, annual variations in water supply that occurred historically because of periods of above- or below-average precipitation. A persistent drought beginning in 2000 raised concern that decreases in runoff entering Lake Powell could follow and releases from Glen Canyon Dam could be severely reduced or constrained. Inflows to Lake Powell on the Colorado River were below average from 2000 through 2004, leading to drawdown of both Lake Powell (figs. 1 and 2) and Lake Mead, the primary flow-regulation structures on the river. On January 27, 2005, the level of Lake Powell was at 3,562.5 ft (1,085.9 m) (full pool capacity is 3,700 ft (1,128 m)), and the reservoir contained 8.5 million acre-feet (maf) (10,481 million m^3) of water (fig. 1), which is only 35% of the reservoir's capacity and a little more than 1 yr of annual flow releases. Reduction in annual flow releases can reduce the water available for prescribed flow releases—particularly flood releases—designed to benefit riverine habitat within Grand Canyon. By 2004, it was speculated that Glen Canyon Dam would be unable to produce hydroelectric power by 2006 or 2007 if drought conditions persisted and the lake level continued to decline.

Conditions changed in fall and winter 2004–05 as a series of storms led to greatly above-average precipitation in the southern portion of the watershed. The high precipitation may have been associated with the onset of El Niño conditions in the Pacific Ocean, which presumably could have enhanced fall and early winter storms. On February 1, 2005, inflows to Lake Powell were forecast to be 125% of normal, the first above-average forecast since 1999. This reversal of conditions

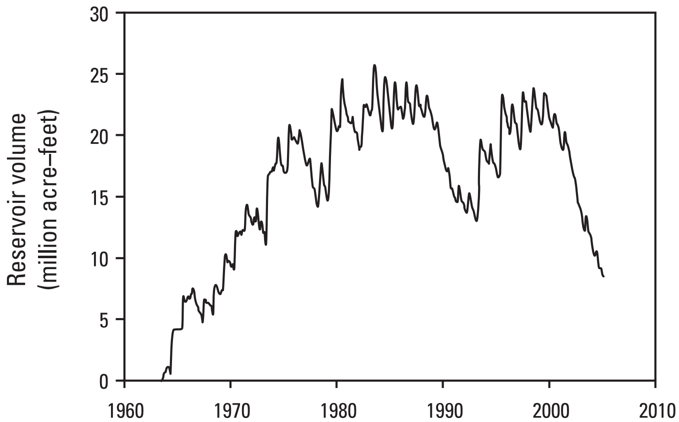

Figure 1. Fluctuations in the level of Lake Powell following closure of Glen Canyon Dam in 1963 (from www.summittech.com/LakePowell/LP_waterDB.php, accessed February 20, 2005).

Figure 2. Lake Powell at Glen Canyon Dam (photograph by Dale Blank, U.S. Geological Survey).

from the previous 5 yr could suggest that the drought is over, although some long-term records suggest that this may not be the case since average years have occurred within periods of extended dryness. To date, it is unclear whether the early 21st century drought is over or not, and the possible persistence and magnitude of the drought are of great concern for the Glen Canyon Dam Adaptive Management Program.

Unfortunately, the factors that caused and sustained the early 21st century drought have not been positively identified. Although conditions in the tropical Pacific Ocean were considered to be ideal for drought conditions in the continental United States (Hoerling and Kumar, 2003), new studies suggest that the Atlantic Ocean may also influence drought (Gray and others, 2004; McCabe and others, 2004). In the case of the Colorado River, it is possible to examine the drought in a broader historical and climatic context, which can be developed through historical records and statistical models. First, a historical record exists of actual observations and estimates of annual flows in the river at various places, including Lees Ferry. Second, scientists have gained an understanding of precipitation patterns by using annual growth rings in trees to reconstruct the hydrologic conditions in a basin several hundred years before the historical record began. Third, climatologists and other scientists have recently developed statistical techniques and dynamical models that improve understanding of the relations between various ocean temperature patterns and observed precipitation patterns.

This chapter makes clear that the drought beginning in 2000 probably had its origins in several hemispheric-scale atmospheric and oceanic processes that affect moisture delivery to the Colorado River Basin (fig. 3). In this context, the chapter describes the general causes of drought in the Southwest, the long-term perspective on drought duration in the basin based on tree-ring reconstructions, the use of global climate indices to explain Colorado River flows, and scenarios of future climate and runoff in the Colorado River Basin.

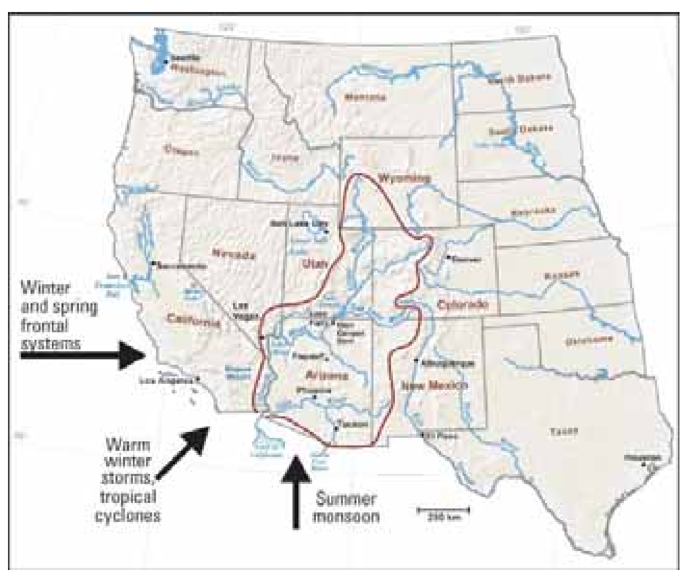

Figure 3. Moisture sources for the Colorado River Basin (outlined in red). Lees Ferry is the separation point between the upper and lower Colorado River Basins as specified in the Colorado River Compact of 1922.

Background

Drought is caused by persistent low precipitation over a region. As such, the severity of a drought is a function of spatial extent, duration, and magnitude of the precipitation deficit. Moreover, the area affected by a drought may shift in space and time. This combination of variable factors makes drought prediction and estimation of drought frequency extremely difficult. The causes of persistent drought over a large drainage basin, such as the Colorado River Basin, are particularly difficult to determine because the basin spans a large latitudinal range.

Sources of Moisture

The most important sources of water to the Colorado River Basin are frontal systems that originate in the North Pacific Ocean and occur in winter and spring. These systems tend to carry moisture at high levels in the atmosphere, and precipitation is orographically controlled, meaning that it typically increases with elevation in the mountains. Cold frontal systems drop substantial amounts of snow at high elevations and rain at low elevations in the Rocky, Uinta, and Wind River Mountains, which in turn become the headwaters of the Colorado River and its principal tributary, the Green River (fig. 3). The frequency and moisture content of frontal systems are strongly affected by the strength of atmospheric circulation patterns and sea-surface temperatures in the Pacific Ocean.

There are two basic types of winter storms that affect flow in the Colorado River. Cold winter storms deliver moisture in the form of snow at most elevation ranges in Utah, Colorado, New Mexico, northern Arizona, and Wyoming. These storms build snowpacks that melt in the spring, providing runoff to the Colorado River. Warm winter storms, originating in the tropical Pacific Ocean, may produce rain on snowpacks, resulting in large runoff events and floods on major rivers, which tend to overwhelm reservoir systems, particularly in Arizona.

Moisture delivered to the Colorado River during summer months typically originates from a combination of the Gulf of Mexico, the Gulf of California, and the eastern North Pacific Ocean. Known variously as the "Arizona monsoon," the "Southwestern United States monsoon," the "summer monsoon," or even the "North American monsoon," this moisture arrives in July and August at low atmospheric levels. The moist air rises rapidly over the desert landscape, spawning high-intensity thunderstorms that produce runoff mostly at elevations of less than 7,000 ft (2,134 m). The thunderstorms tend to be of small spatial extent, and, although they spawn severe flash flooding locally, few floods are generated on larger rivers in the region.

Status and Trends

Flow at Lees Ferry

Flow in the Colorado River measured at Lees Ferry (fig. 3), the political boundary between the upper and lower Colorado River Basins, varied substantially during the 20th century. Calendar-year flow volumes (fig. 4a) were combined from three data sets that were measured or estimated by using different techniques. From 1895 through 1922, annual flow volumes at Lees Ferry were estimated by LaRue (1925, p. 108); from 1922 through 1962, unregulated flow was measured at the Lees Ferry gaging station; and from 1963 through 2004, flow was estimated as the sum of tributary flows entering Lake Powell (Webb and others, 2004). Consumptive water use in the basin upstream of the gage at Lees Ferry is not accounted for in these data. As a result, flow values measured at Lees Ferry are due to climatic fluctuations and changes in consumptive water use in the upper basin States of Wyoming, Colorado, Utah, and New Mexico.

The average annual flow volume shown in figure 4a was 12.3 maf (15,166 million m^3) from 1895 through 2004. This volume is less than the more-commonly quoted annual volume of 15.0 maf (18,495 million m^3) because the time series in figure 4a was not adjusted for water consumed in the upper basin States. The period from 1905 to 1922, which was used to estimate water production allocated under the Colorado River Compact, had the highest long-term annual flow volume in the 20th century, averaging 16.1 maf (19,851 million m^3) at Lees Ferry; however, the highest annual flow volume occurred in 1984 (22.2 maf (27,373 million m^3)), and the highest 3-yr average is 20.3 maf (25,030 million m^3) for 1983 through 1985. The lowest annual flow volume is 3.8 maf (4,685 million m^3) in 2002, followed by 3.9 maf (4,809 million m^3) in 1934 and 4.8 maf (5,918 million m^3) in 1977. The trend in annual flow volume, which decreased by about 0.5 maf (617 million m^3) per decade from 1895 through 2003, is due in part to upstream water consumption.

These data show that flow in the early 21st century is the lowest in more than a century. The current drought has contributed to the lowest flow period on record, producing an average of only 5.1 maf (6,288 million m^3) for the 3-yr period from 2002 through 2004. In contrast, other low 3-yr averages include 6.2 maf (7,645 million m^3) for 1989 through 1991, 6.3 maf (7,768 million m^3) for 1988 through 1990, 7.3 maf (9,001 million m^3) for 1954 through 1956, and 8.0 maf (9,864 million m^3) for 1933 through 1935. The 5-yr average of 5.9 maf (7,275 million m^3) centered on 2002 is the lowest in the 110-yr record. By any measure, the early 21st century drought is the most severe in the unadjusted gaging record.

The Bureau of Reclamation (BOR) adjusted the flow record at Lees Ferry to account for consumptive uses in the upper basin (fig. 4b). In the BOR record, flow volumes are available by water year (October 1 through September 30) for the period of 1905 through 2004, a 99-yr record. The adjusted average annual flow volume at Lees Ferry is 15.0 maf (18,495 million m^3), and the decrease in flow is 350,000 acre-feet (431,550,000 m^3) per decade (fig. 4b). Using this adjusted data, the lowest flow year was 1977 with 5.6 maf (6,905 million m^3), followed by 2002 with 6.4 maf (7,891 million m^3). The 3-yr averages for 2002 through 2004 (9.2 maf (11,344 million m^3)), 2000 through 2002 (9.45 maf (11,652 million m^3)), and 2001 through 2003 (9.51 maf (11,726 million m^3)) are the lowest in the period of record. Similarly, the lowest 5-yr average is 9.9 maf (12,207 million m^3) for 2000 through 2004, which is 1 maf (1,233 million m^3) less than the average flow of the second lowest 5-yr period (1988 through 1992). Using either the actual or adjusted flow values, the early 21st century drought produced the lowest flows of the past century.

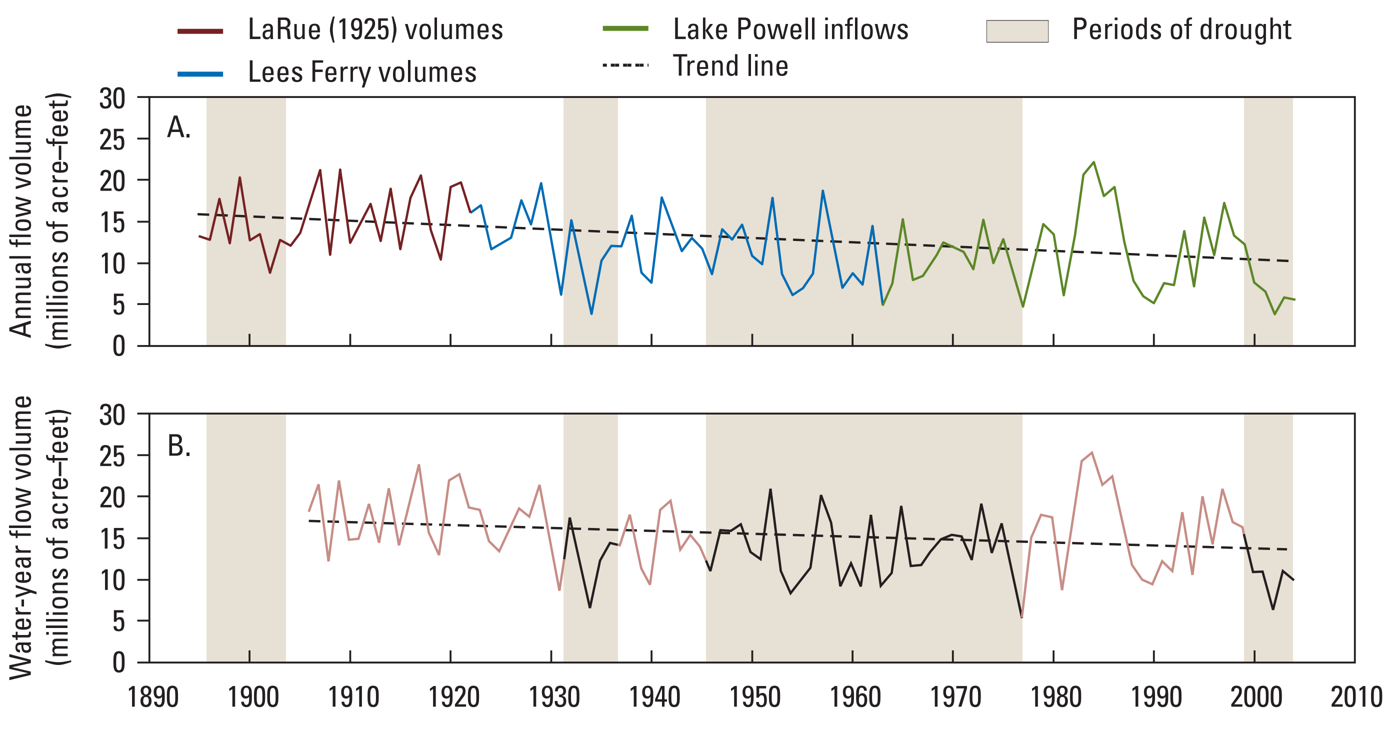

Figure 4. Colorado River flow volume at Lees Ferry (before 1963) and inflows to Lake Powell (after 1963). A. Actual calendar-year flow volumes derived from three sources. From 1895 through 1922, annual flow volumes at Lees Ferry were estimated by LaRue (1925). From 1922 through 1962, flow volumes were measured at Lees Ferry, Arizona. From 1963 to 2004, inflow to Lake Powell was estimated from gaging records on the Colorado River and its major tributaries. B. Water-year flow volumes for Lees Ferry adjusted for consumptive use in the upper basin (Bureau of Reclamation, unpub. data, 2005).

Tree-ring Reconstructions of Drought

Considerable research has addressed the question of the magnitude, frequency, and duration of droughts affecting the Colorado River Basin, including studies examining the effects of the most severe known droughts on record at Lees Ferry (Tarboton, 1995). Many of these studies are based on the seminal work of Stockton and Jacoby (1976), who used dendrochronology to reconstruct long-term river flows using the actual flow record at Lees Ferry for calibration. Recent large-scale work (e.g., Cook and others, 2004), as well as efforts within the drainage basin (Woodhouse, 2003; Gray and others, 2003, 2004), while suggestive, remains insufficient to resolve the basic magnitude-frequency questions concerning the early 21st century drought and its effects on the Colorado River Basin.

What is clear from the Stockton and Jacoby (1976) work and other studies (Salzer, 2000; Woodhouse, 2003; Cook and others, 2004) is how unusual the high precipitation of the early 20th century was in terms of runoff in the Colorado River. The unusually wet period of the 20th century accentuates the severity of the dry conditions experienced during the early 21st century drought. The difference between extreme wet and extreme dry conditions is accentuated because observational records of climate and hydrologic conditions in the Colorado River Basin generally span 100 yr or less, limiting our ability to quantitatively understand the current drought in a long-term context. It is possible, however, to qualitatively view this drought in a long-term context from analysis of tree rings, which provide an indication of moisture conditions going back several centuries.

Using dendrochronological reconstructions from tree rings from the Western United States, Cook and others (2004) analyzed long-term changes in the area affected by drought from A.D. 800 to 2003. Although the region they considered is far larger than the Colorado River Basin and subject to a larger array of climatic influences, their reconstruction provides some perspective on the 2000 through 2004 drought in the Colorado River Basin. Cook and others (2004) concluded that the present drought is not comparable to the so-called “megadroughts” of A.D. 936, 1034, 1150, and 1253, primarily because of its short duration; however, the early 21st century drought may not yet be over. At the very least, their drought-area reconstruction (Cook and others, 2004) suggests that the present drought may surpass other 20th century droughts in the Western United States, including the droughts of the midcentury and the 1930s, and be comparable to droughts of the mid-19th or late 16th centuries.

Several researchers (Tarboton, 1995; Cook and others, 2004; Gray and others, 2004) have noted that decadal-scale persistence of below-average precipitation is of paramount importance when considering drought frequency. Tarboton (1995) and Meko and others (1995) provided data based on the Stockton and Jacoby (1976) reconstructions that, when compared to conditions of 2001–04, suggest that the low-flow conditions of the early 21st century may be the lowest since the drought of A.D. 1579 to 1600.

Recent Findings

Several indices of atmospheric and oceanic processes are used to explain climate variability in the Western United States, including the Southern Oscillation Index (SOI), the Pacific Decadal Oscillation (PDO), and the Atlantic Multidecadal Oscillation (AMO). These indices reflect short- to long-term conditions that can affect the discharge of the Colorado River.

Southern Oscillation Index

Perhaps the most well known of the climatic indices is the Southern Oscillation Index (SOI), which is often used to indicate the status of the El Niño-Southern Oscillation (ENSO) phenomenon in the Pacific Ocean. The SOI is the measure of the strength of tropical Pacific atmospheric circulation based on the sea-level pressure difference between Tahiti, French Polynesia, and Darwin, Australia (fig. 5a). Negative values, implying weakened trade winds, are mainly the result of higher-than-normal surface pressures at Darwin and are associated with El Niño conditions. The impacts of ENSO are felt worldwide through disruption of the general circulation of the atmosphere and associated global weather patterns. In terms of the Colorado River Basin, ENSO affects interannual variation of climate and precipitation in Arizona (Andrade and Sellers, 1988) and helps to explain the occurrence of floods and droughts in the Western United States (Cayan and others, 1998, 1999).

The ENSO is a change between three basic states of the ocean. The warm phase, called El Niño, involves warming of the eastern Pacific Ocean off Peru and the northward spread of warm surface water to the west coast of the United States. Because warming of sea-surface temperatures (SSTs) is a hallmark of El Niño conditions (Knutson and others, 1999), several indices based on SSTs have been developed, including the NINO3 index (fig. 5b). Reduced sea-level pressure over the eastern tropical Pacific Ocean combined with increased sea-level pressure over Indonesia (negative SOI) leads to a weakening in the trade winds, enabling warm water from the central equatorial Pacific Ocean to move toward and along the west coast of South America (positive NINO3 index). The cold phase, called La Niña, is the opposite of the warm phase. Thus, El Niño and La Niña are the warm and cold phases of the ENSO system, which also includes a neutral condition that can persist for several years between the two polar phases. ENSO phases typically last 6–18 mo and are the single most important factor affecting interannual climatic variability on a global scale (Diaz and Markgraf, 1992).

The ENSO also affects atmospheric circulation and SSTs in the eastern Pacific Ocean, which in turn affect the transport of moisture across the Western United States. During El Niño conditions, the warmer-than-average water in the eastern tropical Pacific Ocean and a shift in storm tracks tend to produce above-average precipitation (Redmond and Koch, 1991), above-average runoff (Cayan and Webb, 1992), and, potentially, floods in the Southwest. Not all El Niño events lead to increased runoff, however; during the 2003 El Niño, runoff was below average.

During La Niña events, cooler-than-average SSTs in the eastern tropical Pacific Ocean tend to cause less moisture to flow over the continent, typically causing below-average flow in the Colorado River and predictable below-average precipitation in the Southwestern United States. This below-average precipitation occurs despite a tendency for above-average precipitation in the headwaters of the Colorado River Basin, although precipitation gained is negated by most of the basin having below-average precipitation.

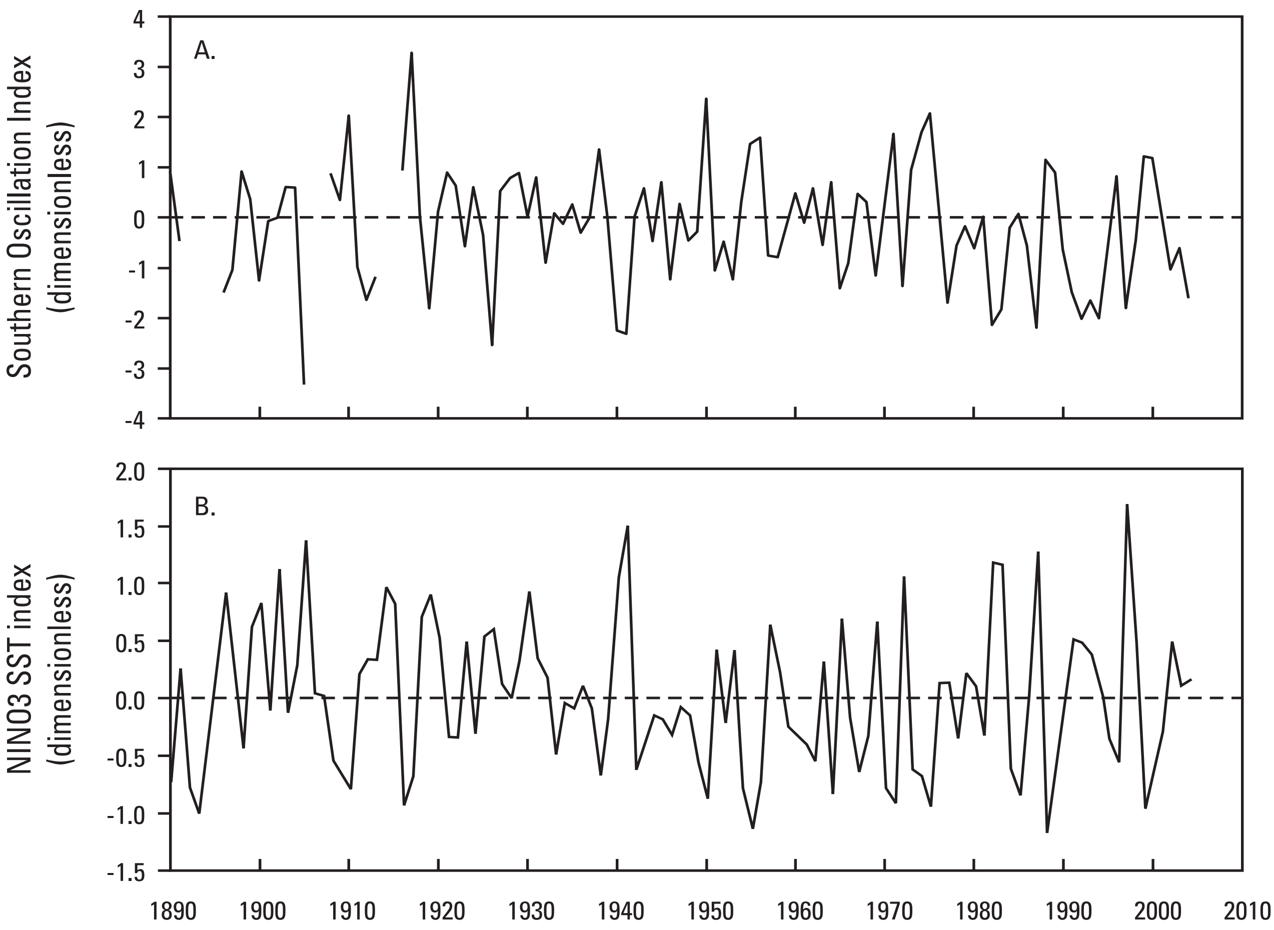

Figure 5. A. The Southern Oscillation Index (SOI) varies with a 4- to 7-yr periodicity between negative (El Niño) and positive (La Niña) states. B. The NINO3 index is a standardized anomaly index of sea-surface temperatures (SSTs) in an area of the equatorial Pacific Ocean from 150°W to 90°W longitude and ±5° latitude centered on the equator. Comparison of these diagrams shows that when SOI is negative, the NINO3 index generally is positive.

Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) index (fig. 6) was developed from SSTs in the Pacific Ocean north of 20°N latitude (Mantua and Hare, 2002). Two main characteristics distinguish the PDO from ENSO: (1) the PDO state (positive or negative) persists for decades, while typical ENSO events persist for 6 to 18 mo; and (2) the climatic signal of the PDO is most visible in the North Pacific Ocean instead of the tropics. The PDO index is commonly used to explain long-term periods of above- or below-average precipitation in the Western United States. When the PDO is positive, there is colder water in the central and western Pacific Ocean and warmer waters in the eastern Pacific Ocean; under negative PDO, the reverse is true. Positive PDO values are usually associated with wetter conditions in the Southwestern United States, while negative PDO values are suggestive of persistent drought in the Southwest. Long-term changes in the PDO may also influence snowmelt runoff in the Western United States, which is occurring earlier in the year, particularly in the Pacific Northwest and in the Sierra Nevada Range of California (Stewart and others, 2005).

Shifts in the phase of the PDO occurred in about 1944 and 1977 (Hereford and others, 2002; McCabe and others, 2004); from 1999 through 2004, PDO values have varied from negative (1999–2001) to positive (2002–04). While this might be viewed as an inconsistency with the persistent drought conditions during that period, the geographic center of drought conditions shifted towards the Pacific Northwest in a manner consistent with a positive (warm) PDO. At present, neither the causes of the variations in PDO values nor their predictability are well known; although, recent studies indicate that the PDO may be associated with decadal-length periods of above- and below-average precipitation and streamflow in the Colorado River Basin (Hidalgo and Dracup, 2004).

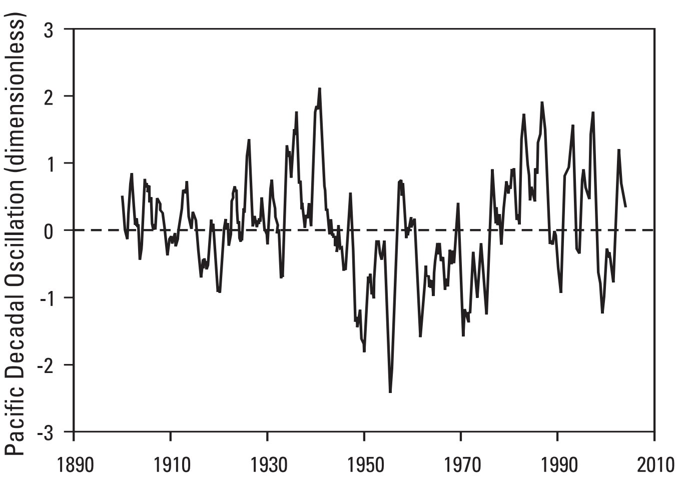

Figure 6. The Pacific Decadal Oscillation (PDO) is typically associated with long-term climatic variation in the Western United States. Positive PDO values suggest wetter periods (e.g., 1976 through 1995) for the Southwest and drier periods for the Northwestern United States. In contrast, negative values suggest persistent drier-than-average conditions in the Southwest (e.g., mid-1940s through mid-1970s).

Atlantic Multidecadal Oscillation

The Atlantic Multidecadal Oscillation (AMO) (Kerr, 2000) reflects conditions in the Atlantic Ocean that may affect climate in the continental United States (fig. 7). The AMO is discussed only to point out that it is an interesting and possibly significant index; much additional research is needed to demonstrate its usefulness. As its name implies, AMO events have a persistence of 20 to 35 yr. Warm conditions indicated by positive AMO values are thought to be associated with drought conditions (Enfield and others, 2001), such as the Dust Bowl on the Great Plains (Schubert and others, 2004) and other periods of drought during the last century (McCabe and others, 2004).

Cool phases in the Atlantic Ocean occurred from 1902 to 1925 and from 1970 to 1994; these periods coincide with generally above-average precipitation and runoff in the Colorado River Basin. A warm phase occurred almost continuously from 1926 to 1963, which coincides with persistent average or below-average rainfall and runoff in the Colorado River Basin between the early 1930s and 1960s. More recently, the Atlantic Ocean warmed in 1996 and remained so through 2004. Fluctuations in the AMO combined with those of the PDO may help explain long-term drought frequency (Gray and others, 2003, 2004) and, therefore, fluctuation in runoff in the Colorado River Basin.

Climate Indices and Drought

As knowledge increases about the influence of the oceans on the climate of the United States, so too does the awareness of the enormous complexity of the ocean-atmosphere system, particularly its variation over time. After intense scrutiny, scientists have learned that no single index of the system can explain all climate variations. It is increasingly evident that the various factors occur together in a complicated fashion. As a result,

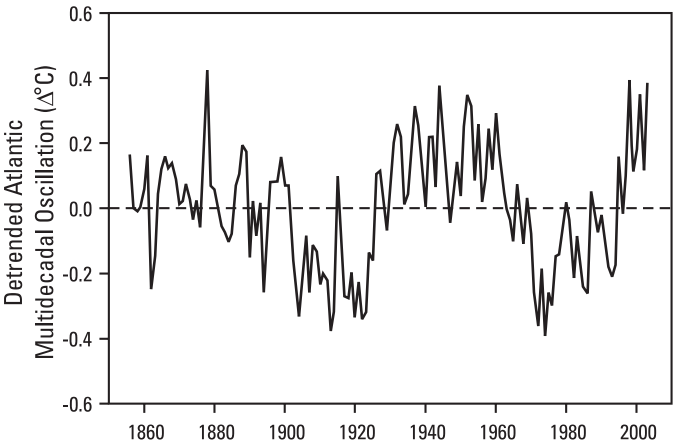

Figure 7. The detrended Atlantic Multidecadal Oscillation (AMO) is related to persistent sea-surface temperature (SST) conditions in the Atlantic Ocean. Positive values are associated with higher-than-average drought frequencies in the United States.

researchers attempt to use a combination of indices to explain the occurrence and spatial extent of droughts (e.g., McCabe and others, 2004).

In terms of the Colorado River Basin, the river's flow is related to the indices of global climate change in a complex way (Hidalgo and Dracup, 2004). From an interannual perspective, large floods and high runoff volumes typically occur during strong El Niño conditions (e.g., 1916–17, 1983–84), whereas La Niña conditions typically cause low-flow conditions (e.g., 1934, 1996). Above-average precipitation during El Niño, however, tends to occur in the southern part of the watershed while the northern part remains dry, a situation that tends to reverse during La Niña conditions.

Furthermore, the watershed of the Colorado River spans more than 10° of latitude, and precipitation patterns over that range do not necessarily respond in concert to regional climatic fluctuations. For example, above-average runoff in part of the watershed (e.g., the northern half) may overcome low runoff in other parts (e.g., the southern half) during some low-flow periods. As a result, much of the variability in the annual flow record is not easily explained by climate indices. For example, the midcentury drought, which was severe on the Colorado Plateau (Hereford and others, 2002), caused only slightly below-average runoff in the entire basin; the average runoff volume during this period was 11.1 maf (13,686 million m^3) for the period from 1948 to 1963. The response of Colorado River flow to the interaction of these climate indices is complicated, underscoring the concept that hydrologic drought results from an integrated set of climatological factors that are not easily predicted or explained.

The predicted effects of future climatic change suggest overall warming conditions and decreased average annual runoff in the basin (Christiensen and others, 2004), although a simple hydrologic response to this complex climatic framework seems unlikely. Predicted temperature increases suggest that snowmelt runoff may be less prevalent and may occur earlier in spring (Stewart and others, 2004, 2005). These analyses raise the possibility that legally mandated flow releases from Glen Canyon Dam may be possible in only 80% of future years owing to climatic change.

Drought Persistence and Relation with Indices of Global Climate

Dendrochronological analyses show that since A.D. 1226, nine droughts have occurred in the Colorado River Basin lasting 15–20 yr and four droughts have occurred lasting more than 20 yr (Gray and others, 2003). Several of these droughts were punctuated by above-average precipitation related to discrete El Niño events, which could be analogous to the effect of current El Niño conditions on the Colorado River Basin. Moreover, tree-ring records indicate that some past droughts in the Colorado River Basin persisted for several decades (Meko and others, 1995), leaving open the possibility that the present drought could resume after the ongoing El Niño ends and continue for many more years.

By using tree-ring records spanning 700 yr, Gray and others (2003, 2004) found 30- to 70-yr multidecadal oscillations in drought frequency in the area that includes the headwaters of the Colorado River Basin. They also found a strong relation between drought occurrence and SSTs in the North Atlantic Ocean as manifested particularly in the AMO index (fig. 7) but which also included the PDO index (fig. 6). While neither index has a strong statistical relation to annual Colorado River flow (fig. 8), the combination may provide a context for the potential duration of the early 21st century drought. The broad relation between the PDO index and drought suggests that the present drought could persist for several decades after the end of the present El Niño period.

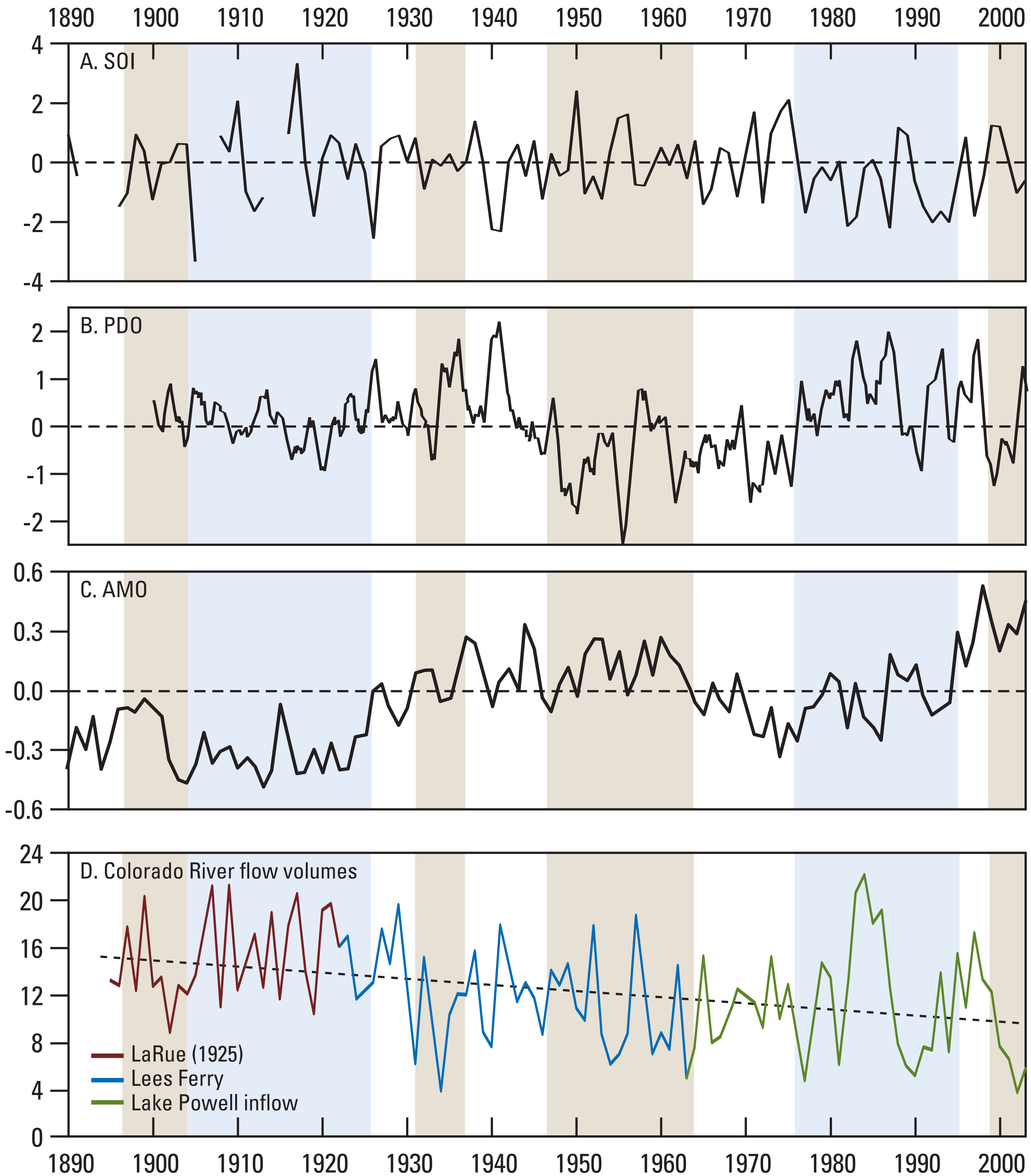

Figure 8. Time series showing the complex interrelations among indices of global climate and annual flow volumes of the Colorado River from 1895 through 2003. Colored vertical bars delineate dry (tan) and wet (light blue) climate periods. A. Southern Oscillation Index (SOI, dimensionless). B. Pacific Decadal Oscillation (PDO, dimensionless). C. Atlantic Multidecadal Oscillation (AMO, deviation in °C), not detrended as in figure 7. D. Actual annual flow volume (in millions of acre-feet (maf)) passing Lees Ferry or entering Lake Powell (fig. 4).

Discussion and Management Implications

From 2000 through 2004, the early 21st century drought caused abnormally low flows in the Colorado River and its tributaries upstream from Lake Powell. By using either actual annual flow data or annual flow records adjusted for consumptive uses in the upper basin, it was found that runoff from 2000 through 2004 was the lowest in the period of record (99–110 yr). This low flow has caused considerable concern about the ability of the reservoirs on the Colorado River to deliver water from upper basin States to lower basin States. Water managers increasingly want to know the predictability of climate and its effects on water resources over annual, decadal, and longer term spans.

Climate, drought, and streamflow in the Colorado River are linked in poorly understood ways. Initial understanding of flows in the system was based on a relatively short historical record that is now believed to be a period of above-average precipitation. Examination of long-term records based on tree-ring analyses suggests that drought magnitude and persistence patterns are associated with much broader hemispheric climate patterns; however, these correlations are imperfect and do not provide a clear understanding of long-term precipitation patterns.

Currently, there is no reliable way to predict how long the early 21st century drought will last in the Colorado River Basin. Components of the climate system, such as sea-surface temperature of the Atlantic and Pacific Oceans, provide some context for understanding past variations in precipitation and streamflow, but they are insufficient for predicting the fate of the ongoing drought. Time series of the relevant climate indices indicate a large amount of year-to-year variability and relatively rapid changes from one regime to another. Above-average precipitation for winter 2004–05 and forecasts for above-average runoff may signal the end of the drought, or the drought conditions may resume after the present El Niño ends. Both outcomes underscore the unpredictability of climatic shifts affecting the Colorado River Basin.

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