Dear Sam,

Just so you hear the other side of the story, I thought I would share my thoughts concerning Grand County Water and Sewer Agency’s new wells and Moab City’s protest. As you know, and stated in your column, Moab City’s concern is valid. I would add that the concern is not only valid, but if the City had not filed a protest it would have neglected its responsibility to the citizens of Moab (and probably residents of Spanish Valley).

The City’s protest was accompanied with a monitoring plan that called for a monitoring well and also a phased-in pumping plan for GCW&SA wells. The City’s water engineers were concerned not only for the quantity of water but how future pumping will affect the quality of Moab’s and Spanish Valley’s water supply. Over pumping can negatively affect both entities’ water quality and quantity.

The City set out a detailed plan that could have been implemented by the State Water Engineer months ago and, more recently, offered an alternate plan. As of yet the Grand County Water & Sewer Agency hasn’t submitted a monitoring plan! The Agency’s administrator and attorney fought the City’s monitoring plans. Perhaps they are the people you should take to task for the current delays.

We all should be concerned about water on the Colorado Plateau. According to a report from the USGS (United States Geological Survey) PRECIPITATION HISTORY OF THE COLORADO PLATEAU REGION, 1900-2000, June 2002...

“Recent trends in Colorado Plateau precipitation ... suggest that climate of the region may become drier for the next 20-30 years in a pattern that could resemble the drought of 1942-1977. Although there are many uncertainties and assumptions, including using a single index (PDO) to predict multi-decadal climate variability (Schmidt and Webb 2001), it is important to consider the potential affects of climate variation on the human and natural resources of the region. Water resources were heavily affected during the early part of the 1942-1977 drought (Fatewood and others 1964): the population of the region has increased fourfold since the mid-1950, substantially increasing the demand for water in a region without abundant supplies and CREATING THE POSSIBILITY OF SEVERE OR CATASTROPHIC CONSEQUENCES IF SUCH A DROUGHT WERE REPEATED”.

Sincerely,
Kyle D. Bailey
Member:
Moab City Council
Grand County Special Service Water District
Grand County Water & Sewer Agency
Climatic Fluctuations, Drought, and Flow in the Colorado River

Introduction

Climatic fluctuations have profound effects on water resources in the western United States (Fig. 1). In the arid and semiarid parts of the 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 (Cayan and others, 1999; Stewart and others, 2004). Since the start of a persistent drought in about the year 2000, inflows to Lake Powell on the Colorado River have been below average, leading to drawdown of both Lakes Mead and Powell, the primary flow-regulation structures on the river (Fig. 2). The recent drought, referred to here as the early 21st century drought, has its origins in several global-scale atmospheric and oceanic processes that reduce delivery of atmospheric moisture to the Colorado River basin. The purpose of this Fact Sheet is to discuss the causes of drought in the Colorado River basin and the predictability of river flows using global climate indices.

Sources of Moisture to the Colorado River Basin

Precipitation is biseasonal (winter and summer) in the Colorado River basin (Fig. 1) on the Colorado Plateau (Hereford and others, 2002). In the headwaters precipitation is evenly distributed across the four seasons, mostly accumulating in snowpacks. Moisture comes from several sources (Fig. 1). Frontal systems in winter and spring originate in the North Pacific Ocean and provide the largest and most important source of moisture. These systems tend to carry moisture at high levels in the atmosphere, and precipitation is orographic, meaning it increases with elevation in the mountainous West. Cold frontal systems produce substantial amounts of snow above about 5,000 feet and rainfall at lower elevations in the Rocky, Uinta, and Wind River Mountains, which are the headwaters of the Colorado River and its principal tributary, the Green River.

Figure 1. Moisture sources to the Colorado River basin.

These storms build snowpacks that melt in the late spring, providing runoff to the Colorado River. Warm winter storms, which originate in the tropical Pacific Ocean, may cause rainfall on snowpacks, resulting in high runoff and floods on major rivers. The frequency and moisture content of frontal systems are strongly affected by atmospheric circulation patterns (particularly their strength) and sea-surface temperature (SSTs) of the tropical and North Pacific Oceans.

Moisture delivered to the Colorado River basin during summer is typically a mixture of moist air from the Gulf of Mexico, the Gulf of California, and the eastern Pacific Ocean. Known as the “Arizona monsoon,” this moisture arrives in July and August at low levels in the atmosphere. The moist air rises rapidly over the desert landscape, spawning thunderstorms that deliver high-intensity rainfall to elevations less than 7,000 feet and lower-intensity rainfall at higher elevations. Thunderstorms tend to be of small spatial extent, and although they spawn severe flash flooding locally, few floods are generated on the larger rivers in the region.

Finally, tropical cyclones, which range from tropical depressions to hurricanes, form in the eastern North Pacific Ocean off the west coast of Mexico. These storms rarely make landfall on the continental United States, instead they dissipate over the ocean. The residual moisture from tropical cyclones, which can be considerable, is either carried inland in weak monsoonal flow during summer months or embedded within stronger cutoff low-pressure systems from the Pacific Ocean. The combination of tropical cyclones and cutoff lows creates conditions for generation of large floods in the southern half of the Colorado River basin.

Indices of Global Climate

Several indices of atmospheric and oceanic processes are used to explain climate variability in the United States. The best-known of these is the El Niño – Southern Oscillation (ENSO) phenomenon in the Pacific Ocean.
The Southern Oscillation Index (SOI) is used to indicate the status of ENSO (Webb and Betancourt, 1992; Cayan and others, 1999). As its name implies, ENSO reflects an oscillation between two basic states of the ocean. The warm phase (negative SOI), called the El Niño, involves warming of the eastern tropical Pacific Ocean off the coast of Peru. The warm water spreads northward in the eastern North Pacific Ocean off the west coast of the United States. The cold phase (positive SOI), called La Niña, is the opposite, resulting in a cooling of the water off western North America. A neutral condition intervenes for several years between the two end states (Fig. 3A).

ENSO reflects interannual variation of climate and helps to explain the occurrence of floods (Webb and Betancourt, 1992) as well as droughts (Cayan and others, 1999). Warm-winter storms tend to be enhanced during El Niño, causing above-average runoff and floods, such as during 1982-1983. Although the incidence of dissipating tropical cyclones tends to be increased during El Niño conditions, the summer monsoon may be diminished in many years. Not all El Niño events lead to increased runoff; for example, runoff during the 2003 El Niño was below average in the Colorado River basin. La Niña conditions, which dominated the period of 1996 through 2002 (punctuated by the El Niño of 1998), caused below-average flow in the Colorado River.

An elaborate index called the Pacific Decadal Oscillation (PDO; Fig. 3B) reflects decadal SST variability and sea-level pressure of the North Pacific Ocean north of 20°N (Manabe and Hare, 2002), and is related to indices of ENSO. The PDO reflects decadal-scale variability and is used to explain long-term periods of above- or below-average precipitation in the region. Shifts in the PDO occurred in about 1944, 1964, and 1977 (McCabe and others, 2004). The recent shift in the PDO in about 1996 is thought to herald a change from wet to dry conditions in the Southwest.

The recently developed index of the Atlantic Multidecadal Oscillation (AMO; Enfield and others, 2001) reflects conditions in the Atlantic Ocean that may affect climate in North America (Fig. 3C). Although the Atlantic Ocean is downstream from the moisture-delivery sources to the Southwest, warm conditions indicated by positive AMO are indicative of drought, for example the Dust Bowl of the early 1930s (Schubert and others, 2004) and at other times during the last century (McCabe and others, 2004). During positive AMO conditions, atmospheric flow is shifted to deliver less moisture to the continental United States. Fluctuations in the AMO, combined with the PDO, may help to explain some of the long-term fluctuations in runoff in the Colorado River basin, while the SOI may explain variation within the shorter-term climatic state.

**Drought and Indices of Global Climate**

Drought is caused by persistent deficits in precipitation over a region. As such, the severity of droughts is a function of spatial extent, duration, and the magnitude of the precipitation deficit. This combination of variables makes drought prediction an extremely difficult proposition. The record of 20th century drought usually is depicted using the Palmer Drought Severity Index (PDSI), which takes into account both precipitation and potential evapotranspiration. Using a state-wide PDSI index (Fig. 3D: National Oceanic and Atmospheric Administration, 2004), the most severe droughts in Utah occurred between about 1896 and 1904, during the early 1940s, between 1948 and 1963 (the mid-century drought), between 1972 and 1976, from 1985 through 1991, and after 1996.

Researchers use a combination of the SOI, PDO, and AMO indices to explain the occurrence and spatial extent of droughts (McCabe and others, 2004). Persistent positive SOI conditions (La Niña) are indicative that a drought of at least short-term duration is going to occur in the Southwest. In contrast, persistent negative SOI conditions, which indicate the occurrence of El Niño, indicate a potential range from drought to extremely wet conditions. However, neither La Niña nor El Niño conditions persist for more than 2-4 years before switching states. Long-term droughts, such as the mid-century event, are associated with persistent negative PDO and positive AMO indices.

**Flow in the Colorado River**

Flow in the Colorado River has varied significantly during the 20th century. Lee’s Ferry (Fig. 1), is the separation point of flow between the upper-basin states of Wyoming, Colorado, Utah, and
New Mexico and the lower-basin states of Nevada, Arizona, and California as determined in the Colorado River Compact of 1922. Calendar-year flow volumes presented in Figure 3E were combined from three data sets that were measured or estimated using different techniques. The primary data for the Colorado River at Lee’s Ferry were collected from the start of streamflow gaging in 1923 through 1962, one year before flow regulation began at Glen Canyon Dam. From 1895 through 1922, we use annual flow volumes at Lee’s Ferry that were estimated by LaRue (1925, p. 108).

From 1963 through 2003, we assume that flow at Lee’s Ferry can be approximated as the sum of flow volumes of the principal rivers flowing into Lake Powell. From 1950 through 1962, comparison of these inflows with measured flow at Lee’s Ferry indicated that the inflow was on average 290,000 acre-feet per year less than the measured flow (about 2% of annual flow volume). Although this is well within measurement error of gaging stations, we used the simple linear regression,

\[ Q_{LF} = 1.044 \cdot Q_{mf} - 0.1688 \quad (R^2 = 0.999) \]

where \( Q_{LF} \) = annual flow volume at Lee’s Ferry and \( Q_{mf} \) = annual inflows to Lake Powell, to increase the inflows to Lake Powell for the period of 1963 through 2003. We also estimated annual volumes for the peak runoff season of April through July (Fig. 3F) for 1923 through 2003 (LaRue (1925) did not estimate monthly volumes).

The time series of flow volumes (Fig. 3E-F) shows that the average annual volume is 12.4 MAF from 1895 through 2003. This volume is less than the more commonly quoted annual volume of 15.1 MAF because our analyses do not include water that is consumptively used in the upper basin states. This usage is partially reflected by regression of annual and seasonal (April through July) flows, which indicate that flow volumes in the Colorado River at Lee’s Ferry have decreased by about 0.5 MAF/decade from 1895 through 2003 (Figs. 3E, 3F).

The period 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 million acre feet (MAF) at Lee’s Ferry. The highest annual flow volume occurred in 1984 (22.2 MAF), and the highest three-year average is 20.3 MAF for 1983-1985. The lowest annual flow volume is 3.8 MAF in 2002, followed by 3.9 MAF in 1934 and 4.8 MAF in 1977. The early 21st century drought is the most severe in terms of flow deficit in more than a century. The current drought also has produced the lowest flow period in the record, with an average of only 5.4 MAF for 2001-2003. In contrast, the drought of the Dust Bowl years between 1930 and 1937 produced an average of 10.2 MAF. The predicted inflow into Lake Powell for 2004 is 49% of the long-term average (5.6 MAF), which indicates that the early 21st century drought is on-going (McCabe and others, 2004).

**Colorado River Flow and Multidecadal Climate Variability**

Colorado River flow is related to

![Graphs showing indices of global climate and annual flow volumes of the Colorado River from 1895 through 2003.](image)
the indices of multidecadal climate variability, although in a complex way. From an interannual perspective, large floods and high runoff volumes typically occur during strong El Niño conditions, whereas La Niña conditions typically cause low-flow conditions (Webb and Betancourt, 1992). Hereford and others (2002) showed that precipitation on the Colorado Plateau is related to both the SOI and PDO indices. Other statistical analyses show that flows in the river only can be partially explained by the PDO (Hidalgo and Dracup, 2004). Our ability to predict water resources in the Colorado River basin remains poor.

As shown in Figure 4, variability in flow of the Colorado River is a complex response to both the AMO and PDO. Above-average flows reliably occur when the AMO index is negative and the PDO index is between -0.5 and +0.5. Below-average flows generally occur when the AMO is positive (Fig. 4). The deepest droughts appear strongly related to a range in AMO index from -1.0 to +1.0 (mostly from 0 to +1.0) and a PDO index of approximately -0.5. Figure 4 underscores the concept that drought results from a complex set of climatological factors that are not easily predicted or explained.

The watershed of the Colorado River spans a large latitudinal range, and precipitation patterns over that gradient do not respond in concert to regional and (or) multidecadal climatic fluctuations. 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 droughts. For example, the mid-century drought, which was severe on the Colorado Plateau, caused only slightly below-average runoff in the entire basin; the average runoff volume during this period was 11.1 MAF. Similarly, the early 20th-century drought (Fig. 3D) produced an average runoff volume of 13.6 MAF. As a result, much of the variability in the annual flow record (Fig. 3E-F) is not easily explained by the PDO and AMO indices despite some compelling graphical relations (Fig. 4).

Dendrochronology and Colorado River Flows

Tree-ring reconstructions of Colorado River flows provide a longer-term flow record that can be used to assess drought frequency. One of the most important conclusions from dendrochronology is that the period from 1906 through 1930, which was partially used to determine flow allocations under the Colorado River Compact, was likely the highest period of runoff in 450 years (Stockton and Jacoby, 1976). This suggests that the most unusual aspect of Colorado River runoff during the 20th century is the high runoff volume in certain periods (1906-1920, 1983-1985), not the drought periods. The decade with the highest annual flow volume (averaging about 9.71 MAF) occurred from A.D. 1584-1593 (Meko and others, 1995). For comparison, the 10-year period of 1995 through 2004 (2004 is a predicted volume) produces an average annual flow volume of 9.9 MAF (not corrected for upstream diversions or use). Similarly, the lowest 5-year average using tree rings is 8.84 MAF (A.D. 1590-1594), compared with 7.11 MAF from 1999 through 2003. These comparisons suggest that the current drought may be comparable to or more severe than the largest-known drought in 500 years.

The wide range of predictions of the persistence of the current drought reflect the poor explanation of past Colorado River flows using dendrochronology. If the primary control on drought in the Colorado River basin is the AMO, then drought conditions might continue for several decades owing to the persistence of SST warming in the Atlantic Ocean (McCabe and others, 2004). Similar arguments are based on persistence of the PDO, although this index is currently positive (Fig. 3B), which suggests that a return to normal or above-average conditions may be imminent. As indicated by the tree-ring reconstructions, droughts persist for longer than a decade, and if that remains the case, the current drought is only half over.

Robert H. Webb, Gregory J. McCabe, Richard Hereford, and Christopher Willkowske

Selected References


INTRODUCTION

The Colorado Plateau, perhaps the most visually captivating part of the continental United States, covers 210,000 km² (130,000 mi²) of Utah, Colorado, New Mexico, and Arizona (fig. 1). Geologically, the Plateau contains extensive areas of colorful, nearly horizontal, and essentially bare sedimentary rocks that are sculpted into plateaus, mesas, and deeply incised canyons of which Grand Canyon is the classic example. The average elevation of the Plateau is 1,500 m (5,000 ft), with peaks over 3,700 m (12,000 ft). The region is arid to semiarid with sparse vegetation in the lowlands, forests in the mountains, and lush riparian vegetation along the watercourses. The spectacular scenery, diverse ecosystems, and numerous important archaeological sites are protected in 30 National Parks and Monuments.

Environmental organizations, ranchers, and agencies responsible for resource management in the National Parks, Monuments, and other Federal and State lands of the region have a need to understand long-term climate and how climate may change in the near future. Regional precipitation varied substantially in the 20th century and is expected to decrease over the next 20–30 years. Scientists from diverse disciplines recently participated in a workshop to consider how landscapes and ecosystems in the Southwest might respond to a drier climate (Schmidt and Webb, 2001). A change to drier climate—particularly reduced winter rainfall—would have a variety of interrelated effects on Plateau ecosystems. These may include reduced groundwater recharge, lower baseflow in perennial streams, increased frequency of dust storms and strong winds, weakening of biological soil crusts, reduction of plant cover and possible changes in species composition, remobilization of sand from previously stable dunes, and increased frequency of forest and range fires. This Fact Sheet discusses the 20th century precipitation patterns of the Plateau, shows their relation to global climatic indices, and points out how precipitation may change in upcoming decades.

LONG-TERM VARIABILITY OF ANNUAL PRECIPITATION

Average annual precipitation on the Colorado Plateau, based on analysis of daily records from 97 long-term weather stations (fig. 1), ranges from 136–668 mm/yr (5.4–26.3 in/yr), with a median precipitation of 300 mm/yr (11.8 in/yr). Annually, precipitation varied substantially during the 20th century (fig. 2). Three multi-decadal precipitation regimes are apparent in the precipitation history: 1905–1941, 1942–1977, and 1978–1998. Although the choice of limiting dates for these regimes is somewhat subjective, the middle period was clearly dry and was sandwiched between two wetter episodes. The early part of the dry regime (1942–1956) was recognized as a drought in the 1960s (Gateswood and others,
1964), perhaps the severest drought in the past 400 years in New Mexico (Swan and Betancourt, 1998). This drought affected much of the Southwest and lasted until 1977, although precipitation gradually increased after 1965. The first five years of the 20th century (1900–1904) was the culmination of an 11-year drought in the Southwest that began in 1895 (Gatewood, 1962).

The annual variability of precipitation is consistent among the stations. Wet years, defined as having precipitation above the 20th century regional median, typically have more than 50 percent of the stations reporting precipitation above the median. From 1942–1977, moisture was below normal at more than 50 percent of the stations for 32 of 36 years. Excluding the 1900–1904 drought and 1999–2000, the relatively wet precipitation regimes (fig. 2) were characterized by wet conditions in 18 of 37 and 14 of 21 years, respectively. Aside from the severe drought of 1969, climate from 1978–1998 was consistently wet compared with the preceding 36 years.

SEASONAL PRECIPITATION

Regional precipitation is biseasonal, occurring mostly during the cool and warm seasons, defined here as October–April and June–October, respectively. Cool-season precipitation is caused primarily by frontal systems originating in the eastern North Pacific Ocean. Warm-season rainfall is related to the Mexican Monsoon, a seasonal reversal of atmospheric circulation that transports moisture over the Plateau from the Gulf of Mexico and (or) the Gulf of California. Seasonal precipitation is expressed in figure 3 as a standardized anomaly index (SAI); indices near zero indicate normal precipitation, while those substantially above or below zero indicate relatively wet or dry conditions. Seasonal precipitation has three multi-decadal patterns similar to those of annual precipitation. The two wet regimes were characterized by several unusually moist seasons, whereas during the 1942–1977 dry regime, neither season was unusually wet except the winter or cool season of 1975.

COLORADO PLATEAU PRECIPITATION AND GLOBAL CLIMATE

Precipitation variability on the Colorado Plateau is linked spatially and temporally with events in the tropical Pacific and Northern Pacific Oceans. Specifically, episodes of unusually wet or dry climate result from interrelated small-scale fluctuations of sea-surface temperature (SST), atmospheric pressure, and atmospheric circulation patterns. These fluctuations operate on two time scales, providing an important means of understanding and predicting precipitation patterns. Short-term climate variation, with a period of 4–7 years, is associated with El Niño and La Niña activity as expressed by several indicators including the Southern Oscillation Index (SOI) and equatorial SST. Multi-decadal climate variation follows a pattern best expressed by the Pacific Decadal Oscillation (PDO), a phenomenon of the Northern Pacific Ocean.

Short-term variation—El Niño and La Niña

The SOI is the standardized difference in sea-level atmospheric pressure between Tahiti and Darwin, Australia. A sustained negative value of the SOI portends the large-scale, anomalous warming of SST in the tropical eastern Pacific Ocean. This phenomenon is generally referred to as El Niño, a term originally applied to the weak, seasonal (usually late December, warm, and south-flowing current off the coast of Peru) (Trenberth, 1997). Warm SST in the eastern equatorial Pacific Ocean and sustained negative SOI indicate El Niño conditions, whereas cool SST and sustained positive SOI indicate La Niña conditions. The fully developed interaction between atmosphere and ocean is termed ENSO (El Niño-Southern Oscillation). El Niño conditions tend to bring wet winters to the Southwest and increased streamflow through southerly displacement of storm tracks, although drought may also occur, whereas La Niña conditions reliably bring dry winters (Cayan and others, 1999).

Seasonal precipitation in the Colorado Plateau region correlates negatively with the SOI (fig. 4). The strength of the correlation is modest, but the probability (P) that precipitation is independent of SOI is negligible (i.e., probability of no relation is less than 0.05 or P < 0.05). A time series of ENSO activity and seasonal precipitation are given in figure 5. Identification of ENSO events and their influence on global and regional climate is the subject of considerable climate research. Indeed, there is no universal definition of what constitutes an ENSO event (Trenberth, 1997). The ENSO chronology plotted in figure 5 is based on the SOI (SOI Indices), SST in the Niño3 (Niño3 Indices) equatorial region of the Pacific Ocean at 5°S–5°N, 160°E–150°W, and the chronologies of Trenberth (1997), Ropelewski (1989), and the Climate Prediction Center (2001). In the following analysis, Colorado Plateau seasonal precipitation was classified as ENSO (El Niño or La Niña) or non-ENSO (i.e., background climate) based on the above sources and the conditions of SST and SOI from the mid-point to six months preceding a particular season.

The details of the relation between ENSO and Colorado Plateau precipitation are complicated and contradictory when examined in detail (fig. 5). Nevertheless, several general relations are statistically significant (P<0.05). During El Niño, the frequency of above normal
Seasonal precipitation (SAI) classified by ENSO or non-ENSO influence as a function of the SOI. Purple, light green, and orange symbols are El Niño, La Niña, and non-ENSO, respectively. SOI was averaged over a 7-month window centered on the mid-point of the season.

Figure 5. ENSO chronology and seasonal precipitation (SAI). SST (upper) and SOI (second from top). Color pattern same as figure 4. SST and SOI were smoothed with 5-month running average with ENSO threshold conditions for SST of 0.4 and -0.3 °C and SOI threshold of ±0.5 standard deviations.

cool-season precipitation increased above the background climate; on the other hand, precipitation during La Niña is typically less than precipitation during El Niño. ENSO activity varies in strength, which in turn affects precipitation (fig. 6). During the cool and warm seasons, weak El Niño was usually associated with below-normal precipitation. The variability of warm-season precipitation during strong El Niño events exceeded non-ENSO conditions. Briefly, in both seasons, strong El Niño episodes increased the variability (warm season) of precipitation or the frequency (cool season) of above normal precipitation relative to non-ENSO climate, whereas strong La Niña episodes typically produced normal, relatively low variability warm-season precipitation and typically below normal cool-season precipitation.

Long-term variation—The PDO

Recent and possible future climate variation related to the PDO and other ENSO-like indicators of multi-decadal climate variability is a recently developed tool for climatological research. The PDO is partly related to SST and atmospheric pressure of the Northern Pacific Ocean (Marotz and Hale, 2002). Changes in these parameters evidently trigger sharp transitions from one climate regime to another, altering the climate of North America for periods of 2-3 decades (Zhang and others, 1997). Phase shifts of the PDO are thought to affect the spatial connection between ENSO and precipitation in the western United States (McCabe and Dettinger, 1999). The PDO is not a completely independent predictor of climate variability because it correlates with and is dependent on ENSO variability, although it produces essentially the same patterns of temporal variability as more robust indicators.

Precipitation in the Colorado Plateau region is modestly correlated (P<0.05) with the PDO (fig. 7). The three precipitation regimes shown by the annual (fig. 2) and seasonal precipitation (fig. 5) times series are largely in-phase with the PDO (fig. 8). This in-phase relation is shown well by the dry episode of 1942-1977, which corresponds to a period of low indices and a prolonged cool phase of the PDO. The early phase of the PDO is associated, although in a complicated manner, with the relatively wet conditions from 1905-1941.
The strong warm phase of the PDO beginning around 1977 is readily associated with the wet climate beginning in 1978. Of particular interest is the downward shift in the PDO beginning in 1999 with concomitant decreased precipitation that continued through the winter of 2002. The wetter, SST, and surface-pressure patterns of the past three years suggest to climatologists that the transition to another regime is presently underway (Ze'ev and Smith, 2001), signaling the end of the warm PDO phase and the wet climate of 1978–1998.

IMPLICATIONS

Precipitation in the Colorado Plateau region has varied substantially during the past century. This multi-decadal variability has implications for ecosystem processes and land management. Precipitation along with other climate variables affects the spatial scale, frequency, and magnitude of natural disturbances to the ecosystem (Swetnam and Betancourt, 1998) as well as the recovery rates from natural and human disturbances. For example, the results of studies of floral and faunal population dynamics and the effects of grazing are dependent on the prevailing climate. Inferences and projections based on these studies may not be valid or may need adjustment or reappraisal if applied during a different climate regime.

Recent trends in Colorado Plateau precipitation and the PDO suggest that climate of the region may become drier for the next 2–3 decades in a pattern that could resemble the drought of 1942–1977. Although there are many uncertainties and assumptions, including using a single index (PDO) to predict multi-decadal climate variability (Schmidt and Webb, 2001), it is important to consider the potential effects of climate variation on the human and natural resources of the region. Water resources were heavily affected during the early part of the 1942–1977 drought (Gatewood and others, 1964); the population of the region has increased fourfold since the mid-1950s, substantially increasing the demand for water in a region without abundant supplies and creating the possibility of severe or catastrophic consequences if such a drought were repeated.

Richard Hereford1, Robert H. Webb2, and Scott Graham1 (GIS)
Flagstaff1 and Tucson2, Arizona
June 2002

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