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Impacts of Climate Change on Water and Ecosystems in the Upper Colorado River Basin

- Colorado River water supports 25 million people and is used to irrigate 3.5 million acres of farmland. Trend analyses predict that human populations dependent on Colorado River water will increase 52% to 38 million by 2020.
- Climate models predict higher temperatures and reduced precipitation for this region, resulting in a decrease in the quantity and quality of Colorado River water. This will impact humans, wildlife, and plants dependent on this water. Less soil moisture will also reduce and alter plant cover needed by livestock and wildlife.
- Land use in low-elevation areas of the Colorado Plateau will further exacerbate this problem. Disturbance of soil surfaces increases wind-deposited dust on snowpack, which accelerates snowmelt. Reduction of water quantity, combined with sediment entering the system from upriver, will further decrease water quality in the Colorado River.

The setting and the issues

Current climate models predict that large changes will occur in the Upper Colorado River Basin (Fig. 1). During this century, it is predicted that precipitation will decrease by 15-20% and temperatures will rise by up to 4-6 °C (Christensen et al. 2007). Such changes will have profound effects on water and living systems in the Colorado River watershed.

Water from the Colorado River currently supplies the needs of 25 million people in seven U.S. states, two Mexican states, and 34 Native American tribes (Pulwarty et al. 2005). However, these regions are experiencing exponential increases in human population, and an increase to 38 million people is expected by 2020. Thus, while demands for water will dramatically increase, the number and severity of droughts, caused by decreasing precipitation and increasing temperatures, will decrease Colorado River flows.

Droughts during 2000-2004, caused by both reduced precipitation and a series of the hottest years on record, resulted in water flows lower than the driest period during the 1930s Dust Bowl or the 1950s drought (Andreadis and Lettenmaier 2006). Increased temperatures alone can also play a major role in reducing water flows in this region. For instance, precipitation received during the winter of 2005 was at the 100-year average. However, low soil moisture and high January-July temperatures resulted in flows that were only 75% of average (National Research Council 2007).

By 2050, increasing temperatures alone are predicted to increase evaporation, resulting in average soil moisture conditions in the Southwest being worse than the conditions experienced during any of the mega-droughts of this century (Dust Bowl years, 1953-1956 or 1999-2004 droughts). Increased warming is expected to decrease runoff by up to 30% through the 21st century (Milly et al. 2005). The major reservoirs on the Colorado River are currently only about 50% full. Models predict that the Colorado River Compact and the U.S. agreements with Mexico will be met only 60% of the time by 2070 (National Research Council 2007). These predictions are conservative; the latest Intergovernmental Panel on Climate Change (IPCC) models are now estimating a much higher rise in temperature for this region than previously expected. In

Figure 1. Colorado River Basin, with the Upper Basin circled in red.

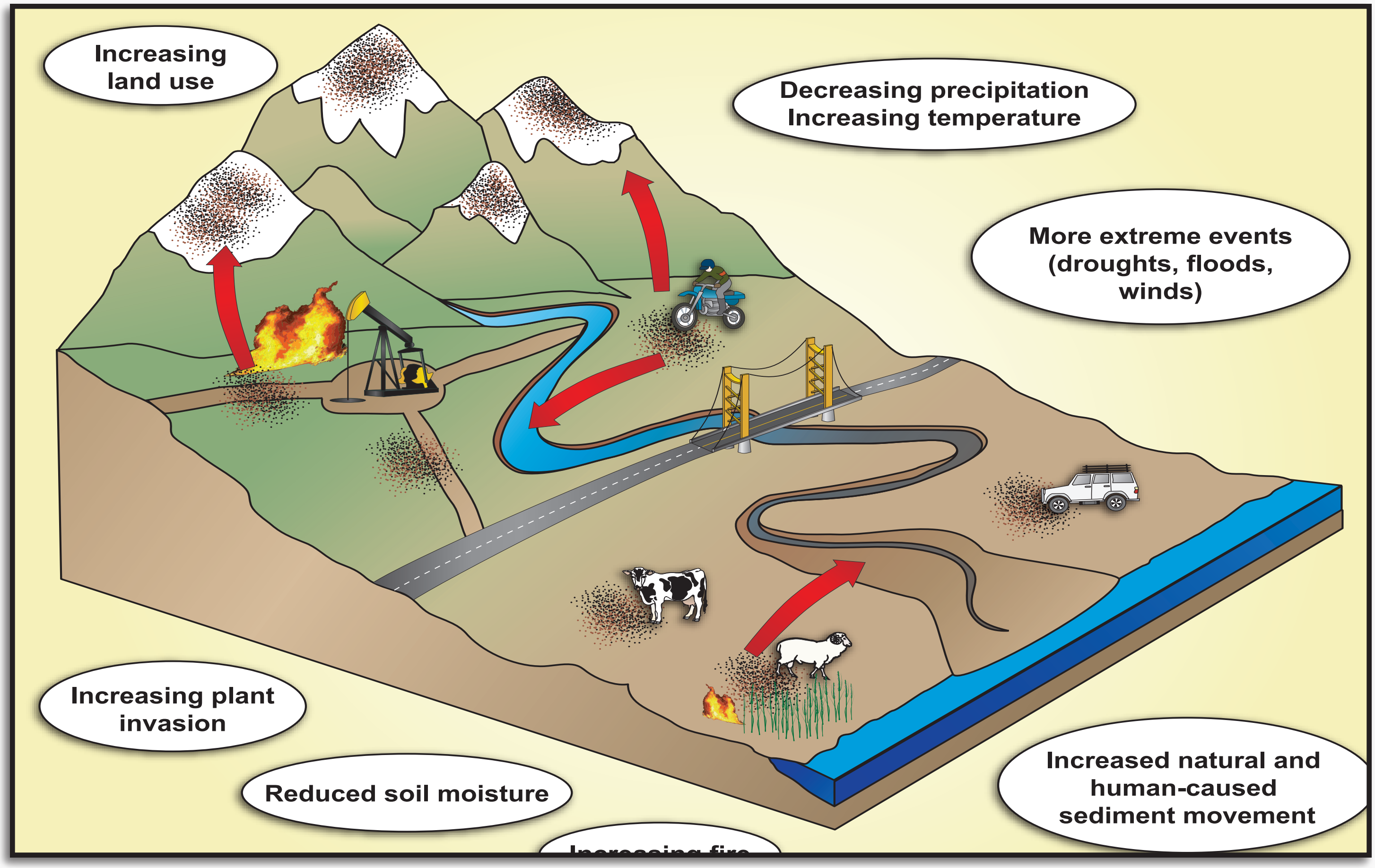

Figure 2. Interaction of climate change, land use, and Colorado River water quantity and quality.

addition, current data suggest that changes are happening much more rapidly than model predictions (Pulwarty et al. 2005).

The lowland regions through which the Colorado River flows are the driest regions of the U.S. Land use, fire, and the invasion of exotic annual grasses in these lower elevation lands will also affect the storage, delivery, timing, quality, and quantity of Colorado River water (Fig. 2). Soil disturbing activities, including grazing, energy exploration/development, and recreation, are increasing dramatically on the Colorado Plateau. These uses reduce or remove the natural components that stabilize desert soils (live and dead plant materials, physical and biological soil crusts, rocks). This increases soil loss through wind and water erosion (Marticorena et al. 1997). Surface disturbance also enhances the invasion of exotic annual grasses. In wet years, these grasses produce sufficient fuels to carry fire in dry years that follow (Fig. 3). Fire consumes the vegetation and leaves post-fire soils exposed to erosion. In drought years, annual grasses do not germinate, leaving soils barren and vulnerable to erosion. A synergistic effect is created when surface disturbance occurs on invaded landscapes during drought years, and large amounts of soil can be lost from an area as a result (Fig. 4). Increasing temperatures and decreasing precipitation also decrease soil and ecosystem resilience to land-use impacts, further increasing the frequency and magnitude of erosion events.

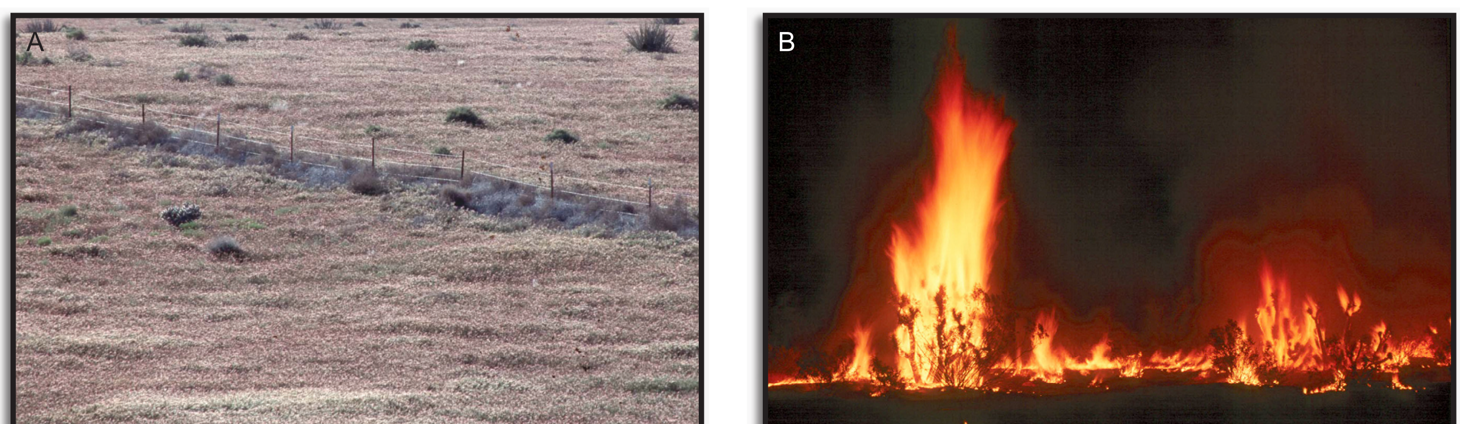

Figure 3. A) This alien annual grassland has burned multiple times in the past three decades. B) These grasses provide fuel for high intensity fires, which can leave the land vulnerable to erosion. (Courtesy of Todd Esque, USGS).

Large dust storms have both local and regional effects (Fig. 5). Soil fertility is lost with the dust, as nutrients are often attached to dust particles. Dust obscures visibility on highways and thus endangers travelers. The fine particles found in dust can cause respiratory disease if inhaled and can also carry Valley Fever. Dust also affects water storage and delivery. Most of the dust produced from the Colorado Plateau is deposited on the snowpack of mountains that feed the Colorado River (Painter 2006). The dark-colored dust on the snow surface absorbs heat, which melts the underlying snowpack up to a month earlier than normal (Figs. 2 & 6). Water storage in the snowpack is reduced, and thus the amount and quality of the later-season water is reduced. A faster melting rate can also mean an increase in flooding and less opportunity to store water in downstream dams.

Exposed soils are also vulnerable to erosion by water. As with dust, water erosion has both local and regional impacts. Locally, water erosion reduces the fertility of the soil and can alter which plant communities the area can support. Massive soil loss can entirely denude areas. Gullying can drop water tables too low for plants to access. Water erosion also increases sediment loads in streams and, ultimately, large rivers. In the Upper Colorado River Basin, these sediments are often heavily laden with salts and heavy metals, contributing to water quality problems downstream. Thus, both wind- and water-borne sediment is likely to severely exacerbate issues regarding the quality and quantity of the Colorado River water.

Altered water quantity, quality, and delivery time will affect humans directly and indirectly. A reduction in water quantity and quality will directly impact the millions of people who depend on Colorado River water for their livelihoods and survival. Biological resources in this region are also at risk. The severe and extended droughts that will accompany an increase in temperatures and a decrease in precipitation will affect all aspects of the dryland ecosystems that dominate this region. For example, ecosystem processes that keep soil carbon and nutrients available will be slowed. Natural and managed systems will both be impacted. Alterations at the base of the food chain will reverberate upwards. The expected loss of nitrogen-fixing organisms and shallow-rooted plant species (e.g., lichens, grasses, some trees) will reduce populations of animals that depend on the quantity and quality of these plants for food and habitat (e.g., small mammals), which will then impact their predators (snakes, larger mammals, raptors). Animals that depend on free surface water (e.g., amphibians, large mammals) will also be at risk. Domestic cattle operations depend on both grass and surface water being available, and thus will be heavily impacted. Insect outbreaks on drought-stressed plants will be more common and will likely lead to a dramatic increase in wildfires. Recovery after fire generally depends on water availability and thus is expected to be much slower than in the past.

Plants and animals directly dependent on Colorado River water are also at risk. The Colorado River is home to several endangered fish species, such as the humpback chub and razorback sucker. Riparian areas that line the river are a lifeline for many desert species, including migratory birds and the endan-

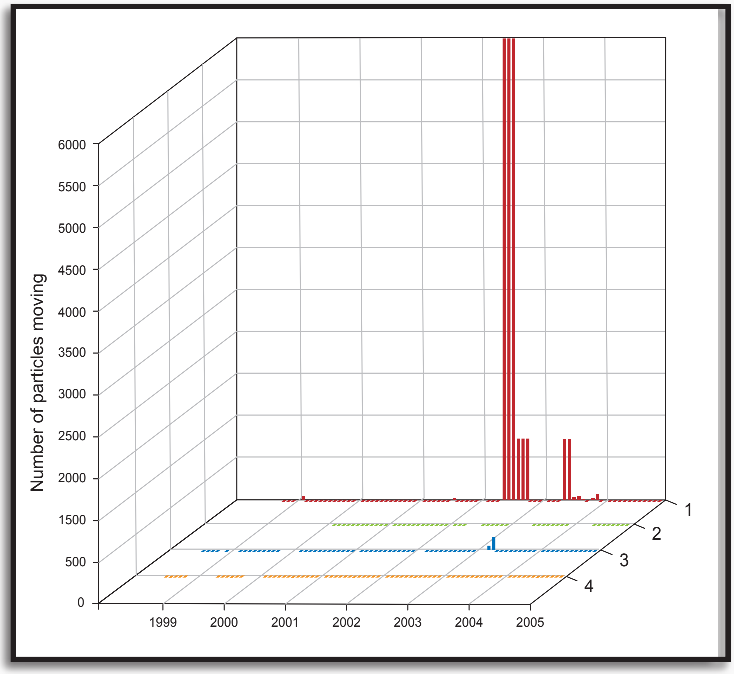

Figure 4. The number of particles moving at four site types: (1) a grazed exotic annual grassland, (2) a grazed native shrubland, (3) an ungrazed exotic annual grassland, and (4) an ungrazed native perennial grassland. Note the large increase in sediment movement during the 2002-2004 drought, when annual grasses did not germinate and soils were disturbed by livestock.

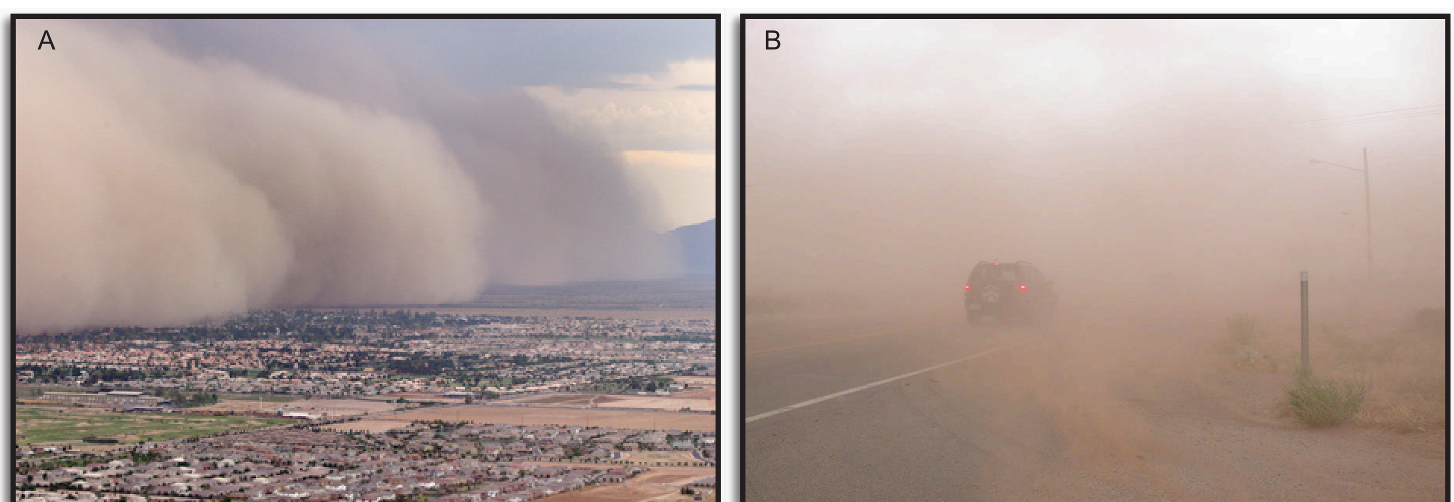

Figure 5. A) Dust storm over Phoenix, July 2006. B) Dust on Highway 191 in southern Utah, June 2006.

gered Southwestern Willow Flycatcher. Extreme climatic events will produce very high and very low water levels, which will both alter riparian areas.

What can be done?

Understanding how climate change will impact our natural resources will enable us to find appropriate management actions to respond to future conditions. To accomplish this, we need to:

- Understand how climate change, and the interaction among climate, land use, invasive biota, and fire, will impact ecosystem processes, soil stability and fertility, plants, wildlife and humans at the local to global scales. This will be done by documenting past climate, land use, land cover, and disturbance regimes (e.g., fire, extreme climate events); expanding existing long-term monitoring of climate, air and water quality (including wind and water borne sediments), soils, ecosystem processes, vegetation, animals, and land use/land cover; and simulating future conditions with manipulative research techniques.
- Understand the interactions between hydrology, climate, land use, and vegetation that increase sediment movement. Measure effects on water storage (in soils, ground water, aquifers, and snowpack), delivery (timing, intensity, and duration) and quality (salinity, heavy metals, sediment load) in the Upper Colorado River watershed. Document impacts of altered hydrologic cycles on terrestrial and aquatic resources. This will be done by expanding current monitoring of water quantity and quality at different scales within the watershed, expanding current aquatic and terrestrial resource monitoring, and determining the sources and sinks for mobilized sediment.
- Model future climate change at the regional and local scale and use the understanding of the interactions discussed above to forecast future conditions in relation to changing climate, land use, disturbance, and land cover.
- Research types of land management that will better meet future challenges.
- Establish a collaborative adaptive management and modeling group, consisting of policy makers, land managers, scientists, and the public, to examine the potential consequences of alternative management scenarios.
- Communicate these findings to other policy makers, land managers, scientists, and the public.

Partners

USDA Forest Service, US Geological Survey (Geography, Geology, Biological and Water Resources), Bureau of Land Management, Bureau of Reclamation, National Oceanic and Atmospheric Association, National Park Service, The Nature Conservancy, Brigham Young University, University of Utah, Utah State University, University of Colorado, Boulder.

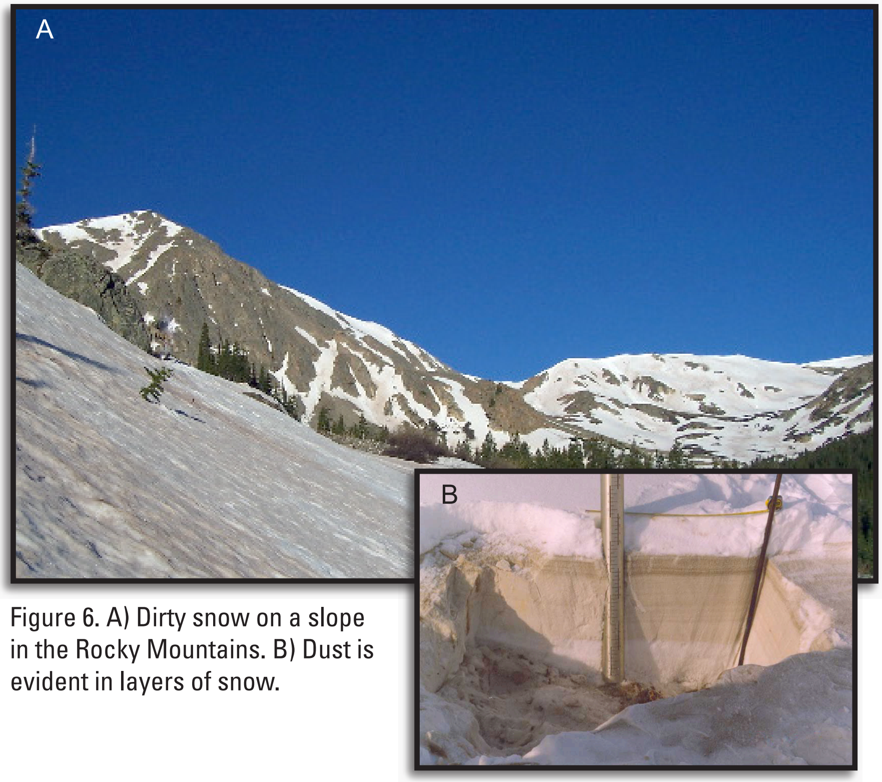

Figure 6. A) Dirty snow on a slope in the Rocky Mountains. B) Dust is evident in layers of snow.

References

Andreadis, K.M., and D.P. Lettenmaier. 2006. Trends in 20th century drought over the continental United States: Geophysical Research Letters, 33: L10403.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr, and P. Whetton. 2007. Regional climate projections, in S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller, eds. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, Cambridge University Press, p. 848-940.

National Research Council, Committee on the Scientific Bases of Colorado River Basin Water Management. 2007. Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability. Washington, D.C., National Academies Press.

Marticorena, B., G. Bergametti, D. Gillette, and J. Belnap, 1997. Factors controlling threshold friction velocity in semiarid and arid areas of the United States. Journal of Geophysical Research, 102 (D19): 23277-23287.

Milly, P.C.D., K.A. Dunne, and A.V. Vecchia. 2005. Global pattern of trends in streamflow and water availability in a changing climate. Nature, 438 (7066): 347-350.

Painter, T. H., A. Barrett, J. Neff, and C. Landry. 2006. Radiative forcing by dust deposition in mountain snow cover. European Geosciences Union, Paper no. EGU06-A-09824.

Pulwarty, R., K. Jacobs, and R. Dole. 2005. The hardest working river: Drought and critical water problems in the Colorado River Basin, in D. Wilhite, ed. Drought and Water Crises: Science, Technology and Management. CRC Press, Boca Raton, Florica, p. 249-285.