Climate Change in Colorado

A Synthesis to Support Water Resources Management and Adaptation

A REPORT FOR THE COLORADO WATER CONSERVATION BOARD

Colorado
University of Colorado at Boulder

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A REPORT BY THE WESTERN WATER ASSESSMENT FOR THE COLORADO WATER CONSERVATION BOARD

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EXECUTIVE SUMMARY

The scientific evidence is clear: the Earth's climate is warming. Multiple independent measurements confirm widespread warming in the western United States; in Colorado, temperatures have increased by approximately 2°F between 1977 and 2006. Increasing temperatures are affecting the state's water resources. (Sections 1, 2, 4, 5, 6)

THIS REPORT is a synthesis of climate change science important for Colorado's water supply. It focuses on observed trends, modeling, and projections of temperature, precipitation, snowmelt, and runoff. Climate projections are reported out to the mid-21st century, because this is a relevant time frame for development of adaptation strategies.

Although many published studies and datasets include information about Colorado, few climate studies focus only on the state. Consequently, many important scientific analyses for Colorado are lacking. This report summarizes Colorado-specific findings from peer-reviewed regional studies, and presents new graphics derived from existing datasets. The state is home to many experts in climate and hydrology, and this report also draws from ongoing work by these scientists.

Observations, Attribution, and Projections

- Changes in Colorado's climate and implications for water resources are occurring in a global context. On a global scale, climate change has been linked to observed and projected changes in the water cycle. By the mid-21st century, average river runoff and water availability are projected to increase at high latitudes and decrease over dry regions at lower midlatitudes such as the western United States. Changes in the quantity and quality of water may occur due to warming even in the absence of precipitation changes. (Section 1)
- The accumulation of greenhouse gases (including carbon dioxide) in the atmosphere is ***very likely*** the cause of most of the increase in global average temperatures (IPCC AR4 WGI 2007). In North America, temperatures have increased by 2°F in the last 30 years, and "human-induced warming has ***likely*** caused much of the average temperature increase over the past fifty years" (CCSP SAP 3.3 2008, p. 3). (Section 5)
- In Colorado, temperatures have increased about 2°F in the past 30 years. All regions examined within the state warmed during the last 30 years, except the far southeast corner, in which there was a slight cooling trend. (Section 2)
- Climate models show a 1°F warming in the West over the last 30 years in response to greenhouse gas emissions from human activities (anthropogenic). However no studies have specifically investigated whether the detected trends in Colorado can be attributed to anthropogenic greenhouse gases. (Sections 2, 4)
- Climate models project Colorado will warm 2.5°F [+1.5 to +3.5°F] by 2025, relative to the 1950–99 baseline, and 4°F [+2.5 to +5.5°F] by 2050. The 2050 projections show summers warming by +5°F [+3 to +7°F], and winters by +3°F [+2 to +5°F]. These projections also suggest that typical summer monthly temperatures will be as warm as or warmer than the hottest 10% of summers that occurred between 1950 and 1999. By way of illustration, mid-21st century summer temperatures on the Eastern Plains of Colorado are projected to shift westward and upslope, bringing into the Front Range temperature regimes that today occur near the Kansas border. (Section 5)
- Winter projections show fewer extreme cold months, more extreme warm months, and more strings of consecutive warm winters. Typical projected winter monthly temperatures, although significantly warmer than current, are between the 10th and 90th percentiles of the historical record. Between today and 2050, typical January temperatures of the Eastern Plains of Colorado are expected to shift northward by ~150 miles. In all seasons, the climate of the mountains is projected to migrate upward in elevation, and the climate of the Desert Southwest to progress up into the valleys of the Western Slope. (Section 5)
- In all parts of Colorado, no consistent long-term trends in annual precipitation have been detected. Variability is high, which makes detection of trends difficult. Climate model projections do not agree whether annual mean precipitation will increase or decrease in Colorado by 2050. The multi-model average projection shows little change in annual mean precipitation, although a seasonal shift in precipitation does emerge. (Sections 2, 5)
- A widespread and large increase in the proportion of precipitation falling as rain rather than snow, and reduction in snow water equivalent (SWE) have been observed elsewhere in the West. In Colorado, however, these changes are smaller and not as significant. Most of the reduction in snowpack in the West has occurred below about 8200 ft.

However, most of Colorado's snowpack is above this elevation, where winter temperatures remain well below freezing. (Section 2)

- Projections show a precipitous decline in lower-elevation (below 8200 ft) snowpack across the West by the mid-21st century. Modest declines are projected (10–20%) for Colorado's high-elevation snowpack (above 8200 ft) within the same timeframe. (Section 5)
- Between 1978 and 2004, the spring pulse (the onset of streamflows from melting snow) in Colorado has shifted earlier by two weeks. Several studies suggest that shifts in timing and intensity of streamflows are related to warming spring temperatures. The timing of runoff is projected to shift earlier in the spring, and late-summer flows may be reduced. These changes are projected to occur regardless of changes in precipitation. (Sections 2, 5)
- Recent hydrology projections suggest declining runoff for most of Colorado's river basins in the 21st century. However, the impact of climate change on runoff in the Rio Grande, Platte, and Arkansas Basins has not been studied as extensively as the Colorado River Basin. (Section 5)
- The lowest five-year period of Colorado River natural flow since records began in the late 1800s occurred in 2000 to 2004 (9.9 million acre feet per year). Recent hydrologic studies of the Upper Colorado River Basin project multi-model average decreases in runoff ranging from 6% to 20% by 2050 compared to the 20th century average, although one statistical streamflow model projects a 45% decline by 2050. The range of individual model projections within a single study can include both increasing and decreasing runoff due to the range of climate model output used to drive the hydrology models. Ongoing studies are attempting to resolve methodological differences in order to reduce the range of uncertainty in runoff projections. (Sections 2, 5)
- Throughout the West, less frequent and less severe drought conditions have occurred during the 20th century than revealed in the paleoclimate records over the last 1000 years. Precipitation variations are the main driver of drought in Colorado and low Lake Powell inflows, including the recent drought of 2000–07, and these variations are consistent with the natural variability observed in long-term and paleoclimate records However, warming temperatures may have increased the severity of droughts and exacerbated drought impacts. (Sections 4, 5)
- Because global climate models do not represent the complexity of Colorado's topography, researchers are using "downscaling" and other techniques to study processes that matter to Colorado water resource managers. Several projects are underway to improve regional understanding: Some use statistical "downscaling" methods, which adjust for the effects of elevation and the mountains on snowfall and temperature; other studies involve compiling, calibrating, and studying historical datasets; others involve enhanced climate modeling efforts to include finer spatial resolution that better represents Colorado's mountainous terrain. (Section 3)

SIDEBAR ES-1. Communicating Uncertainty

Recognizing the difficulty in communicating scientific uncertainty to those outside the community, climate assessments now make statements designed to communicate probability. The so-called likelihood terminology indicates "the assessed likelihood, using expert judgment, of an outcome or a result" (IPCC AR4 WGI 2007, p. 3). The likelihood terminology quoted in this document follows two different but similar conventions, shown below.

It is important to recognize that the likelihood terminology used here is independent of consequence; these are not risk statements and the consequences of potentially cascading effects are not implicit in the likelihood statements.

The authors and editors of this report did not develop likelihood statements independently. Here, all likelihood statements are quoted from three major assessments (IPCC AR4 WGI 2007, IPCC 2008, CCSP SAP 3.3) where long-term processes involving large panels of experts arrived at conclusions based on the best available science.

Statements quoted from IPCC AR4 WGI and the IPCC Technical Paper on Water use this convention:	Statements quoted from CCSP SAP 3.3 use an intentionally less discrete system:
virtually certain (>99%)	
extremely likely (>95%)	
very likely (>90%)	*very likely* (about 75–100%)
likely (>66%)	*likely* (about 60–75%)
*more likely than not** (>50%)	
*about as likely as not** (>33-66%)	
unlikely (<33%)	*unlikely* (about 25–40%)
very unlikely (<10%)	*very unlikely* (about 0–25%)
extremely unlikely (<5%)	
*exceptionally likely** (<1%)	

* these likelihood terms used by IPCC are not quoted in this report

Implication for Water Resource Managers

Climate change will affect Colorado's use and distribution of water. Water managers and planners currently face specific challenges that may be further exacerbated by projected climate changes. The implications of climate change in this report are consistent with the broader conclusions in the CCSP SAP 4.3, the IPCC Technical Paper on Water (2008), and the 2007 National Academy of Science Report "Colorado River Basin Water Management."

This report provides a scientific basis to support further studies of water resources impacts. However, the assessment and quantification of specific climate change impacts on water resources is beyond the scope of this document.

A synthesis of findings in this report suggests a reduction in total water supply by the mid-21st century. When combined with temperature increases and related changes in evaporation and soil moisture, all recent hydrologic projections show a decline in runoff for most of Colorado's river basins by the mid-21st century. (Section 6)