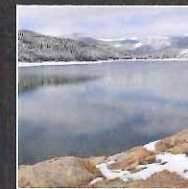
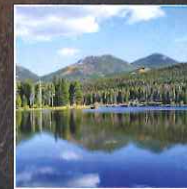
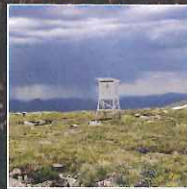


Climate Change in Colorado

*A Synthesis to Support Water Resources
Management and Adaptation*



A Report for the Colorado Water Conservation Board

Executive Summary

Adapted from the Report



Western Water Assessment



University of Colorado
Boulder



COLORADO
Colorado Water
Conservation Board
Department of Natural Resources

Climate Change in Colorado

A Synthesis to Support Water Resources Management and Adaptation

Second Edition - August 2014

A Report for the Colorado Water Conservation Board

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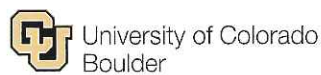
Figures

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Executive Summary

This report is a synthesis of climate science relevant for management and planning for Colorado's water resources. It focuses on observed climate trends, climate modeling, and projections of temperature, precipitation, snowpack, and streamflow. Climate projections are reported for the mid-21st century because this time frame is the focus of adaptation strategies being developed by the State of Colorado and other water entities.

Overview

In the past 30 years, Colorado's climate has become substantially warmer. The recent warming trend in Colorado is in step with regional and global warming that has been linked to increasing atmospheric concentrations of greenhouse gases. Annual precipitation, which has high natural variability, has not seen a statewide trend over that period. However, some drought indicators have worsened due to the warmer temperatures.

As greenhouse gases and other human effects on the climate continue to increase, Colorado is expected to warm even more by the mid-21st century, pushing temperatures outside of the range of the past century. The outlook for future precipitation in Colorado is less clear; overall increases or decreases are possible. The risk of decreasing precipitation appears to be higher for the southern parts of the state.

The future warming is projected to generally reduce Colorado's spring snowpack, cause earlier snowmelt and runoff, and increase the water use by crops, landscaping, and natural vegetation. While future increases in annual natural streamflow are possible, the body of published research indicates a greater risk of decreasing streamflow, particularly in the southern half of the state.

Summit Lake Park, along Mount Evans Scenic Byway.
Photo: Creative Commons, Matt Wright.



Observed climate trends in Colorado (Section 2)

- Statewide annual average temperatures have increased by 2.0°F over the past 30 years and 2.5°F over the past 50 years (Figure ES-1). Warming trends have been observed over these periods in most parts of the state.
- Daily minimum temperatures in Colorado have warmed more than daily maximum temperatures during the past 30 years. Temperatures have increased in all seasons.
- No long-term trends in average annual precipitation have been detected across Colorado, even considering the relatively dry period since 2000.
- Snowpack, as measured by April 1 snow-water equivalent (SWE), has been mainly below-average since 2000 in all of Colorado's river basins, but no

long-term (30-year, 50-year) declining trends have been detected.

- The timing of snowmelt and peak runoff has shifted earlier in the spring by 1–4 weeks across Colorado's river basins over the past 30 years, due to the combination of lower SWE since 2000, the warming trend in spring temperatures, and enhanced solar absorption from dust-on-snow.
- The Palmer Drought Severity Index (PDSI) shows a trend towards more severe soil-moisture drought conditions in Colorado over the past 30 years, reflecting the combination of the below-average precipitation since 2000 and the warming trend.
- No long-term statewide trends in heavy precipitation events have been detected. The evidence suggests that there has been no statewide trend in the magnitude of flood events in Colorado.

FIGURE ES-1. Colorado statewide annual temperature, 1900–2012

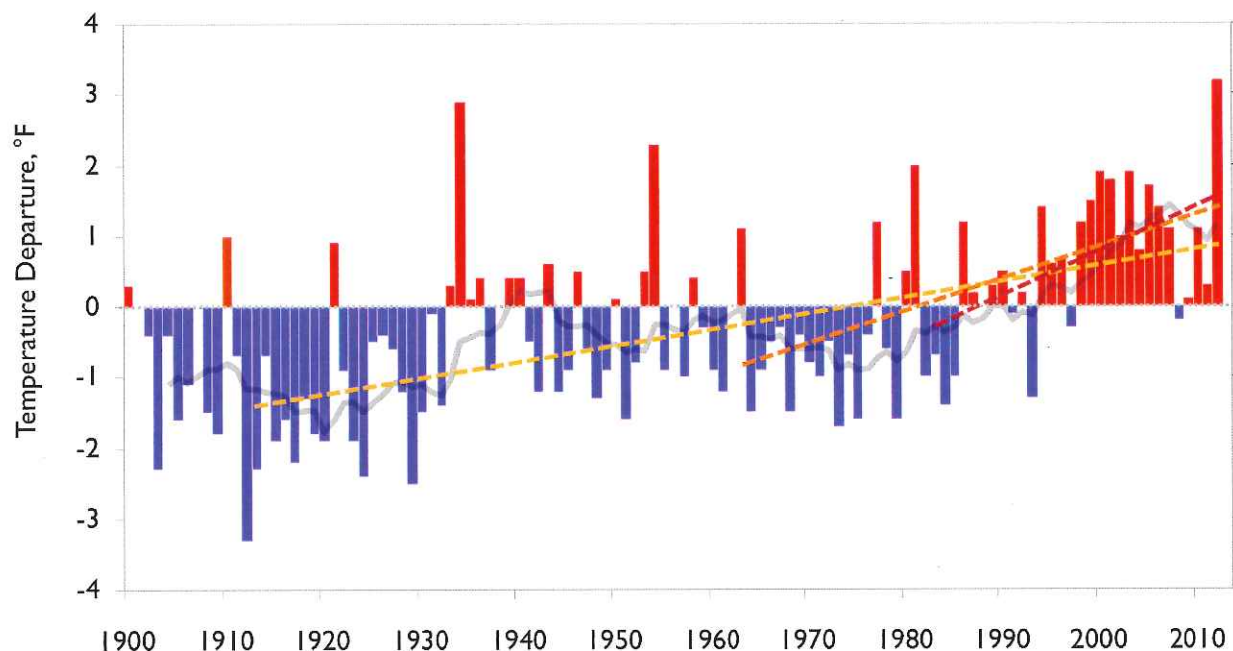


Fig. ES-1. Colorado statewide annually-averaged temperature (°F), 1900–2012. Annual departures are shown relative to a 1971–2000 reference period. The light-orange, orange, and red lines are the 100-year, 50-year, and 30-year trends, respectively. All three warming trends are statistically significant. The gray line shows the 10-year running average. The record shows a cool period from 1900 to 1930, a warm period in the 1930s and again in the 1950s, a cool period in the late 1960s and 1970s, and consistently warm temperatures since the mid-1990s. (Data source: NOAA NCDC; <http://www.ncdc.noaa.gov/cag/>)

- Tree-ring records and other paleoclimate indicators for Colorado show multiple droughts prior to 1900 that were more severe and sustained than any in the observed record.

Linking changes in Colorado to global changes (Section 4)

- The global climate system has warmed since 1900, particularly in the past 30 years, as evidenced by increased surface, atmospheric, and ocean temperatures; melting glaciers and ice sheets; rising sea levels; and increased atmospheric water vapor.
- These global changes have been attributed mainly to anthropogenic (human-caused) influences, primarily the increase in greenhouse gases in the atmosphere to the highest levels in at least 800,000 years.
- In North America, temperatures have increased by about 2°F in the last 30 years, with anthropogenic influences making a substantial contribution.

- In Colorado, temperatures have also warmed by 2°F in the past 30 years. The statewide warming is plausibly linked to anthropogenic influences, but definitive attribution at this spatial scale is difficult.
- Recent variability in Colorado's annual precipitation has not exhibited trends that might be attributed to anthropogenic climate change.
- Anthropogenic climate change may have increased the severity of recent drought conditions in the western U.S., due to the influence of the warming on snowpack, streamflow, and soil moisture.

Projections of Colorado's future climate and implications for water resources (Section 5)

- All climate model projections indicate future warming in Colorado (Figure ES-2). The statewide average annual temperatures are projected to warm by +2.5°F to +5°F by 2050 relative to a 1971–2000 baseline under a medium-low emissions scenario

FIGURE ES-2. Projected annual temperature and precipitation changes for the western U.S. for 2050

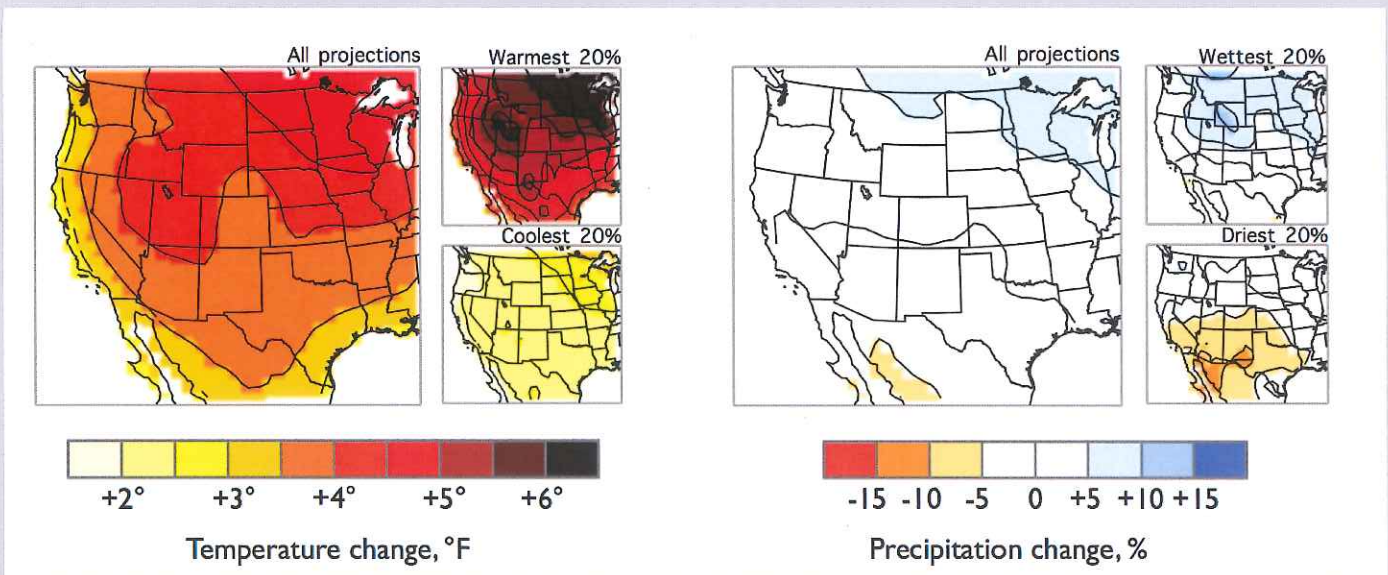


Fig. ES-2. Projected changes in annual-average temperature and precipitation by 2050 (2035–2064) over the western US from an ensemble of 37 climate models under RCP 4.5, a medium-low emissions scenario. The large maps show the average change for all of the models ($n=37$), and the small maps show the average changes for the highest 20% ($n=8$) and lowest 20% ($n=8$) of the models, based on the statewide change for Colorado. For Colorado, all models show substantial warming, but there is less agreement about the direction of precipitation change. See Figure 5-1 for an expanded version that also shows seasonal changes. (Data source: CMIP5 projections re-gridded to 1-degree grid, Reclamation 2013; <http://gdo-dcp.ucllnl.org/>)

(RCP 4.5). Under a high emissions scenario (RCP 8.5), the projected warming is larger at mid-century (+3.5°F to +6.5°F), and much larger later in the century as the two scenarios diverge.

- Summer temperatures are projected to warm slightly more than winter temperatures. Typical summer temperatures by 2050 are projected under RCP 4.5 to be similar to the hottest summers that have occurred in past 100 years.
- Climate model projections show less agreement regarding future precipitation change for Colorado. The individual model projections of change by 2050 in statewide annual precipitation under RCP 4.5 range from -5% to +6% (Figure ES-2). Projections under RCP 8.5 show a similar range of future change (-3% to +8%).
- Nearly all of the projections indicate increasing winter precipitation by 2050. There is weaker consensus among the projections regarding precipitation in the other seasons.
- In the first projections of future Colorado hydrology based on the latest climate model output, most projections show decreases in annual streamflow by 2050 for the San Juan and Rio Grande basins. The projections are more evenly split between future increases and decreases in streamflow by 2050 for the Colorado Headwaters, Gunnison, Arkansas, and South Platte basins. However, other hydrology projections show drier outcomes for Colorado, and the overall body of published research indicates a tendency towards future decreases in annual streamflow for all of Colorado's river basins.
- The peak of the spring runoff is projected to shift 1–3 weeks earlier by the mid-21st century due to warming. Late-summer flows are projected to decrease as the peak shifts earlier. Changes in the timing of runoff are more certain than changes in the amount of runoff.
- Most projections of Colorado's spring snowpack (April 1 SWE) show declines for the mid-21st century show due to the projected warming.
- Most climate projections indicate that heat waves, droughts and wildfires will increase in frequency and severity in Colorado by the mid-21st century due to the projected warming.

Incorporating climate change information into vulnerability assessment and planning (Section 6)

- Colorado water entities have been at the forefront of incorporating climate change into long-term planning, and their experience can inform future efforts by others.
- Observed records of climate and hydrology are still fundamental to assessing future climate risk, but should be supplemented with information from climate model projections and paleoclimate records.
- Planning approaches that explore multiple futures, rather than assuming a single future trajectory, are more compatible with climate projections and may improve preparedness for a changing climate.
- The uncertainty in projections of precipitation and streamflow for Colorado should not be construed as a "no change" scenario, but instead as a broadening of the range of possible futures, some of which would present serious challenges to the state's water systems (Table ES-1).

To download the full report, go to:

[http://cwcb.state.co.us/
environment/climate-change/](http://cwcb.state.co.us/environment/climate-change/)

Supplemental information is available at:

[http://wwa.colorado.edu/climate/
co2014report/](http://wwa.colorado.edu/climate/co2014report/)

TABLE ES-1. Summary of projected changes and potential impacts to water resources for Colorado

Element	Projected changes and potential impacts	Studies that have assessed this vulnerability for Colorado
Overall surface water supply	Most projections of future hydrology for Colorado's river basins show decreasing annual runoff and less overall water supply, but some projections show increasing runoff. Warming temperatures could continue the recent trend towards earlier peak runoff and lower late-summer flows.	CWCB (2012); Reclamation (2012); Woodbury et al. (2012)
Water infrastructure operations	Changes in the snowpack and in streamflow timing could affect reservoir operations, including flood control and storage. Changes in the timing and magnitude of runoff could affect the functioning of diversion, storage, and conveyance structures.	CWCB (2012); Reclamation (2012)
Crop water demand, outdoor urban watering	Warming temperatures could increase the loss of water from plants and soil, lengthen growing seasons, and increase overall water demand.	CWCB (2012); Reclamation (2012)
Legal water systems	Earlier and/or lower runoff could complicate the administration of water rights and interstate water compacts, and could affect which rights holders receive water.	CWCB (2012)
Water quality	Warmer water temperatures could cause many indicators of water quality to decline. Lower streamflows could lead to increasing concentrations of pollutants.	EPA (2013)
Groundwater resources	Groundwater usage for agriculture could increase with warmer temperatures. Changes in precipitation could affect groundwater recharge rates.	
Energy demand and operating costs	Warmer temperatures could place higher demands on hydropower facilities for peaking power in summer. Warmer lake and stream temperatures, and earlier runoff, could affect water use for cooling power plants and in other industries.	Macknick et al. (2012)
Forest disturbances in headwaters regions	Warmer temperatures could increase the frequency and severity of wildfire, and make trees more vulnerable to insect infestation. Both have implications for water quality and watershed health.	
Riparian habitats and fisheries	Warmer stream temperatures could have direct and indirect effects on aquatic ecosystems, including the spread of non-native species and diseases to higher elevations. Changes in streamflow timing could also affect riparian ecosystems.	Rieman and Isaak (2010)
Water- and snow-based recreation	Earlier streamflow timing could affect rafting and fishing. Changes in reservoir storage could affect recreation on-site and downstream. Declining snowpacks could impact winter mountain recreation and tourism.	Reclamation (2012); Battaglin et al. (2011); Lazar and Williams (2008)

Table ES-1. Potential water-related impacts from climate change in different areas and sectors. See the *References* section of the full report for the studies cited in the last column.

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