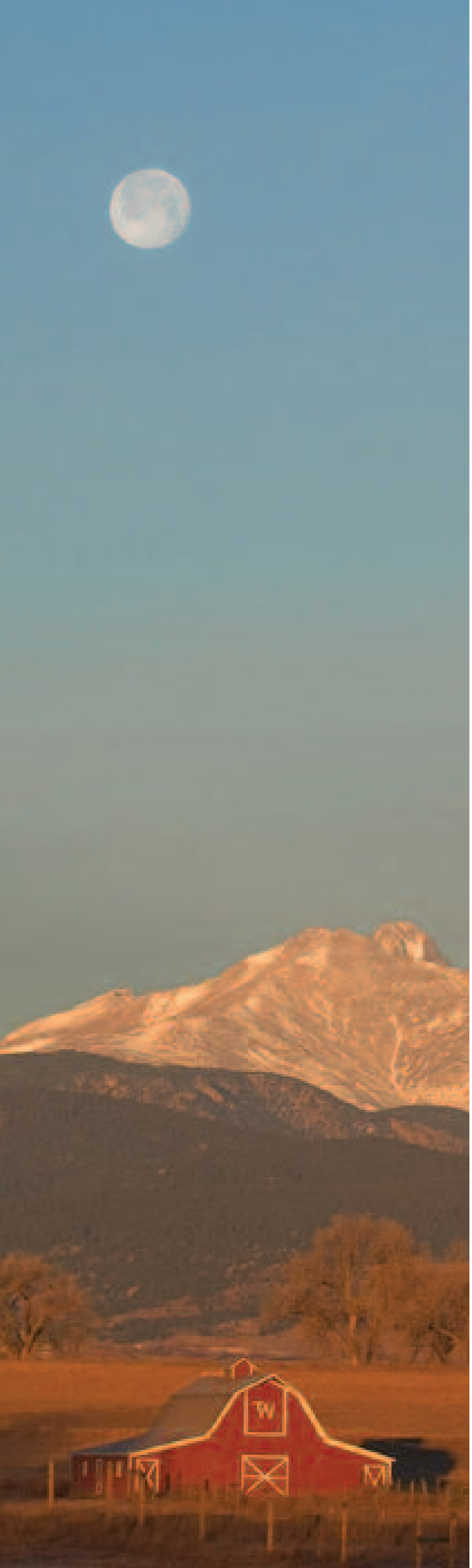

# 6
# Implications of Changing Climate for Colorado's Water Resources

***Colorado's water resources are sensitive to the changing climate on a range of time scales. As a buffer against natural seasonal and interannual variability, Colorado pioneers and their descendants developed infrastructure for water storage and conveyance, and adopted institutional arrangements capable of allocating shortages when necessary, including the prior appropriations system and interstate compacts. These actions helped in managing water during drought and other climate variations in the 20th century. But the 21st century climate may pose new challenges to water managers that are unlike those experienced in the 20th century.***

Paleoclimate studies reveal that previous centuries were unlike the past century. Lengthy droughts and wet periods were more common from about 800 to 1900 in the West (Figure 2-8). Even in the absence of climate change this new understanding of past hydrology would warrant a renewed focus on drought planning. Second, water supply systems are facing complex stresses, including increasing demands from a growing population and potential energy development. Third, these challenges are magnified by the need to consider climate change. Therefore, there is an emerging need for vulnerability assessments, for adaptation planning, and for bringing climate change information into ongoing integrated resource planning.

This report provides a synthesis of the physical aspects of changing climate and a scientific basis to support further studies of water resources impacts. The assessment and quantification of specific climate change impacts on water resources is beyond the scope of this document. Few published studies address potential water resources impacts in Colorado. Two of these—Aspen and Boulder (Sidebars 5.1 and 3.2)—are examples of how climate change information has been considered in water-related resource planning. However, much further work is needed to assess the multi-dimensional impacts and cascading effects on water resources affecting humans and the environment. A number of projects are in progress, such as the Joint Front Range Climate Change Vulnerability Study (JFRCCVS, Sidebar 3.3) and the Colorado River Water Availability Study (**http://ibcc.state.co.us/Process/Needs/WaterSupplyAvailability/**), in which climate projections are being used to explore possible water supply scenarios to which managers may need to adapt.

Section 6 identifies some implications of climate change for Colorado water management. It also briefly discusses the potential uses of the information within this report in water resources management, including assessing vulnerabilities and creating adaptive strategies, such as those called for in the Governor's Colorado Climate Action Plan.

## Key Implications

Climate change will affect Colorado's use and distribution of water. Changes in economies and land use, environmental concerns, and population growth are already affecting water management decisions. Water managers and planners currently face specific challenges that may be further exacerbated by projected climate changes (TABLE 6-1). The implications of climate change in this report are consistent with the broader conclusions in the CCSP SAP 4.3 and the report, *Colorado River Basin Water Management* (NRC 2007).

The consistent projections for a substantial temperature increase over Colorado (IPCC 2008) have important implications for water management. Increases in temperature imply more evaporation and evapotranspiration leading to higher water demands for agriculture and outdoor watering. Temperature-related changes in the seasonality of streamflows (e.g., earlier runoff) may complicate prior appropriation systems and interstate compact regimes; and modify the interplay among forests, hydrology, wildfires, and pests (e.g., pine beetles).

The wide range of precipitation projections makes it difficult to assess likely changes in annual mean precipitation by mid-21st century. However, a synthesis of findings in this report suggests a reduction in total water supply by then. Furthermore, there is potential for increased drought severity in the region due to higher temperatures alone. When combined with temperature increases and related changes in evaporation and soil moisture, recent hydrologic studies on climate change in the Upper Basin of the Colorado River point to an expected decline in runoff by the mid-to-late 21st century. These studies report multi-model average decreases ranging from 6% to 20% by 2050 (Section 5-3). This synthesis is consistent with the conclusion of the IPCC that globally the negative impacts of climate change on water resources outweigh the positive (IPCC 2008).

## Strategies for Incorporating Climate Information into Water Planning and Adaptation

Two pathways for integrating climate information into water resources planning and management are vulnerability analysis and integrated resource planning (see Cromwell et al. 2007; Miller and Yates 2006). Vulnerability analysis includes *top-down* or *bottom-up* perspectives. In the top-down perspective, projections of global or spatially downscaled models are used to drive resource models and project resource impacts. The top-down strategy is illustrated in FIGURE 3-5, which depicts how climate projections may be used in water operations models. Some approaches include the use of sensitivity studies based on changing temperature and/or precipitation by a fixed amount guided by the range of model projections, the direct use of climate model output with existing downscaling methods (e.g., the Aspen Study, SIDEBAR 5-1), and the use of conditionally re-sampled historical record that shifts the average climate according to the model projections, while preserving the character of day-to-day and year-to-year historical sequences.

**TABLE 6-1. Challenges Faced by Water Managers, and Projected Changes**

| *Issues* | *Observed and/or Projected Change* |
|---|---|
| Water demands for agriculture and outdoor watering | Increasing temperatures raise evapotranspiration by plants, lower soil moisture, alter growing seasons, and thus increase water demand. |
| Water supply infrastructure | Changes in snowpack, streamflow timing, and hydrograph evolution may affect reservoir operations including flood control and storage. Changes in the timing and magnitude of runoff may affect functioning of diversion, storage, and conveyance structures. |
| Legal water systems | Earlier runoff may complicate prior appropriation systems and interstate water compacts, affecting which rights holders receive water and operations plans for reservoirs. |
| Water quality | Although other factors have a large impact, "water quality is sensitive both to increased water temperatures and changes in patterns of precipitation" (CCSP SAP 4.3, p. 149). For example, changes in the timing and hydrograph may affect sediment load and pollution, impacting human health. |
| Energy demand and operating costs | Warmer air temperatures may place higher demands on hydropower reservoirs for peaking power. Warmer lake and stream temperatures may affect water use by cooling power plants and in other industries. |
| Mountain habitats | Increasing temperature and soil moisture changes may shift mountain habitats toward higher elevation. |
| Interplay among forests, hydrology, wildfires, and pests | Changes in air, water, and soil temperatures may affect the relationships between forests, surface and ground water, wildfire, and insect pests. Water-stressed trees, for example, may be more vulnerable to pests. |
| Riparian habitats and fisheries | Stream temperatures are expected to increase as the climate warms, which could have direct and indirect effects on aquatic ecosystems (CCSP SAP 4.3), including the spread of in-stream non-native species and diseases to higher elevations, and the potential for non-native plant species to invade riparian areas. Changes in streamflow intensity and timing may also affect riparian ecosystems. |
| Water- and snow-based recreation | Changes in reservoir storage affect lake and river recreation activities; changes in streamflow intensity and timing will continue to affect rafting directly and trout fishing indirectly. Changes in the character and timing of snowpack and the ratio of snowfall to rainfall will continue to influence winter recreational activities and tourism. |
| Groundwater resources | Changes in long-term precipitation and soil moisture can affect groundwater recharge rates; coupled with demand issues, this may mean greater pressures on groundwater resources. |

**FIGURE 6-1. Approaches to Climate Change Assessment**

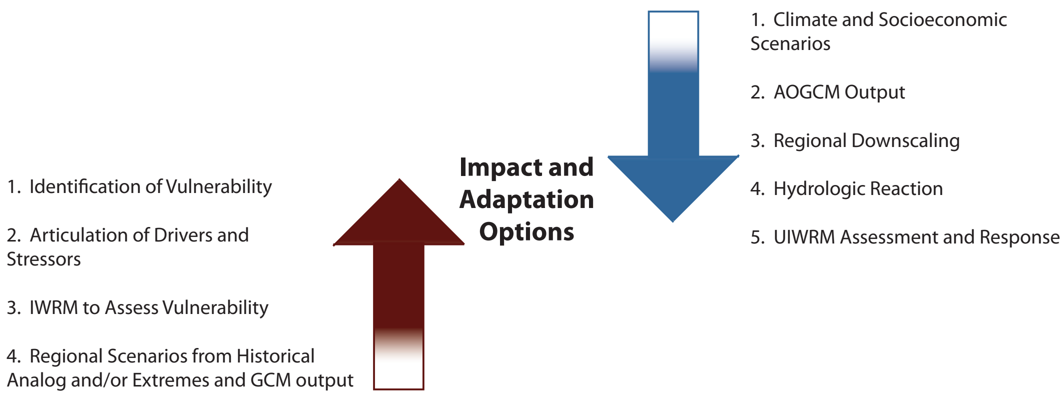


**Fig. 6-1.** Bottom-up and top-down approaches to climate change assessment. These approaches are not necessarily exclusive. (Yates and Miller 2006)

Information from global climate model simulations is beginning to be used in water resource related planning studies, such as the Environmental Impact Study supporting the recent Record of Decision on Colorado River Interim Guidelines (DOI 2007, see **http://www.usbr.gov/lc/**). This report assessed the state of knowledge with regard to climate change and modeling to support planning for operations under long-term drought conditions (Bureau of Reclamation 2007). Miller and Yates (2006) find that most efforts to incorporate climate change information into their planning process have used the top-down perspective. These top-down perspectives, however, are limited by the current state of the art of climate models, downscaling techniques, and observations.

Another approach is often referred to as bottom-up, illustrated in Figure 6-1. Bottom-up approaches are place-based and deal with specific resources of interest, as described for agriculture by Pielke et al (2007). In this approach water managers start with their knowledge of their system and utilize their water supply planning tools to identify what changes in climate would be most threatening to their long-range plans or operations. These are the system's critical vulnerabilities, such as the types of changes in climate that would cause these critical problems e.g., a 10% increase in flow from the 100-year flood. This is known as the threshold approach. The next step is to assess what adaptations can be made to cope and roughly at what cost. By examining the outputs of climate models or studies, water managers can then assess the likelihood of such system critical vulnerabilities.

Climate change information can be incorporated into either top-down scenario-driven or bottom-up vulnerability assessments. In the case of water resources, these assessments might include the risks of compact calls in Colorado's river basins or the risks of large-scale drought. Integrated planning processes based on these might include mitigation planning to assess and prepare for drought and developing for each major river basin a mechanism to deal with potential interstate compact calls.

The information in this report can be used to generate climate vulnerability assessments for Colorado water management that are consistent with the IPCC and CCSP reports. There remain uncertainties in projections of temperature, precipitation, and runoff; model formulation; emissions scenarios; and the role of natural variability.

Therefore, water managers will have to make plans based on a range of possible futures. This uncertainty suggests incorporating climate information in Integrated Resource Planning (IRP) (Cromwell et al. 2007; Yates and Miller 2006). IRP is a widely used long-term planning approach that integrates multiple facets of water management challenges, and is a strategy for keeping a wide range of options open and maintaining flexibility in the face of uncertain futures. This strategy is important given the uncertainties about climate futures. While the science continues to advance, the information will always have uncertainties, a range of possible futures, and there will still be natural variability across time scales. Lempert and Collins (2007) recommend decision pathways that are robust for a range of conditions.

## Key Unresolved Issues

The current state of the science is unable to provide sufficient information to decision makers and stakeholders on a number of crucial scientific issues regarding Colorado's water resources. Often, there are insufficient data, in time or space, to assess long-term observational trends. In other cases, research is in progress, but the results may not be as robust as needed. Four overlapping areas with unresolved issues are climate models, research specific to Colorado, drought, and reconciling hydrologic projections.

- **Modeling issues.** To produce model projections at the scale desired by decisionmakers, regional and local processes and their role in Colorado's climate must be better modeled. Precipitation projections and related phenomena are key uncertainties. Enhanced climate modeling efforts to include finer spatial resolution are needed that better represent Colorado's mountainous terrain and precipitation processes.
- **Colorado-specific research.** Further research is needed focused on the state of Colorado and its river basins, and specifically on regions where there is little or no work, such as the basins of the Arkansas, Rio Grande, and the North and South Platte Rivers.
- **Understanding the causes of drought.** Issues include runoff efficiency, effects of increased temperatures, and uncertainty in precipitation projections. The attribution of the 2000s drought is an area of ongoing research.
- **Hydrologic projections for the Colorado River.** There is a large range among projections of river flows (Section 5). A key uncertainty is how efficient future runoff will be in the Colorado as well as other basins. A study is underway to reconcile the differences among these projections, and to better resolve projections for future flows. These uncertainties arise both from climate models and hydrologic models.

## A View Toward the Future

This is a challenging time for both climate science and water management in Colorado. A warming climate will amplify Colorado's water related challenges, with potential reductions and seasonal shifts in water availability. While most water resource planning has been based on past hydrology, water users can no longer assume that future conditions will reflect the past. Although there are uncertainties regarding aspects of the science, enough information is available to support adaptation planning for risks associated with climate variability and change. Understanding of climate change in Colorado is evolving and many projects are underway to reduce these uncertainties. A continuing dialogue among climate scientists, water resources managers, planners, and policymakers will ensure that the robust scientific findings benefit society.

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