COLORADO CLIMATE PREPAREDNESS PROJECT

FINAL REPORT

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Executive Summary

Climate variability and change introduce risks and uncertainty, as well as potential opportunities, to many activities central to Colorado's economy. Attention to climate variability and change varies across agencies and sectors, yet overall there is widespread awareness of the value of reducing the state's vulnerability to climate impacts. Climate change is beginning to factor into strategic plans, and the state is engaged regionally and nationally in climate assessments and efforts to shape policy so as to reduce vulnerabilities across multiple sectors. Colorado can draw on a unique combination of in-state strengths in climate, energy and natural resources research and management.

Using documents and information obtained through a series of 22 structured interviews, the Colorado Climate Preparedness Project provides a catalog of climate impacts and adaptation activities and options in five climate-sensitive sectors in the state of Colorado: water; wildlife, ecosystems and forests; electricity; agriculture; and outdoor recreation. The following is a summary of key points from the project, overarching recommendations, key points and options that emerged either explicitly or implicitly from the interviews within each sector and from background materials, and key lessons from other states.

Key Points That Emerged from the Project

- Because many climate impacts cross sectors and traditional agency boundaries, adaptation will require coordination across the state government as well as with other entities including the federal government, other states, regional efforts, nongovernmental organizations (NGOs) and municipalities.

- Monitoring is a critical element of climate adaptation, and includes both tracking climate variability and change at spatial and temporal scales that allow assessment of impacts and planning of adaptive responses, and monitoring the effectiveness of those adaptations.

- Additional research on the impacts of climate change on physical, ecological, economic, and legal systems is a need common to all sectors. Also, research is needed to anticipate the unintended consequences of climate adaptation and mitigation.

- A more complete impacts and vulnerability assessment centered on a range of plausible climate scenarios to prioritize Colorado's key climate threats and vulnerabilities could point to adaptations that could reduce costs and potential losses.

- Climate impacts on water resources—e.g., changes in runoff patterns, snowpack, and storage—are a significant source of impacts to the other four sectors examined in this report.

- The state is already engaged in many activities that are not explicitly driven by climate adaptation but that might create resilience to the impacts of climate.

- Communication between stakeholders and the state about climate change impacts and response strategies emerged as another important element of an overall adaptive strategy.

- A recurring theme across the sectors is the challenge faced by planners and managers as they attempt to incorporate climate change into decision making. Even agencies that explicitly and successfully incorporate climate variability into planning are struggling with the inherent uncertainty of long-term climate projections and the incompatibility of the timescales of climate change with existing planning regimes.

Overarching Recommendations

The following overarching recommendations are derived from our synthesis of the interviews and documents reviewed. It is beyond the scope of this project to prioritize or identify funding sources for recommendations and options included in this report.

- The governor should set the tone for climate adaptation efforts by providing leadership and resources.

- The governor should weigh the pros and cons of appointing a separate climate change adaptation coordinator. The current climate change coordinator position has largely focused on mitigation, reflecting the priorities of the Climate Action Plan.

- Adaptation efforts need flexibility across agencies in order to be successful. Such flexibility must be supported from the governor's office.

- Water supply impacts are somewhat known, cut across multiple sectors and could provide a focus for a statewide impacts and vulnerability assessment.

- Alternatively, a multi-sector statewide impacts and vulnerability study could focus attention on climate sensitivities in multiple sectors, including those where our understanding is weak.

- Climate science is constantly evolving and should be tracked and integrated into planning on a continuing basis to reflect updated research findings.

- Though more and better climate information is coming, we know enough about the likely direction and magnitude of climate change impacts relevant to many sectors to move forward with an initial cycle of adaptation planning in many areas.

- The state should actively engage with several federal initiatives including the new National Climate Assessment, the Landscape Conservation Cooperatives, and the Climate Science Centers, both to bring the state's insights to bear and to benefit from these larger efforts.

- To encourage additional exchange of information, as well as collaboration across a range of interests, the state should provide resources to maintain and enlarge the database and wiki developed as part of this project.

Key Points from the Sector Chapters[1]

Water

- Among state agencies, the Colorado Water Conservation Board (CWCB) has the most prominent adaptation role in this sector.

- The most serious anticipated impacts of climate change include shifts in timing and intensity of streamflows and runoff, reductions in late-summer flows, decreases in runoff, increases in drought, and modest declines for Colorado's high-elevation snowpack.

- Most state agencies in this sector are working to explicitly incorporate climate adaptation into their strategic planning and activities, most notably CWCB.

- Among the significant barriers to implementing adaptation planning in this sector are (1) gaps in climate and hydrology monitoring; (2) gaps in hydrology and climate--related research on changes in extreme events, demands, runoff, and groundwater-surface water interactions; (3) gaps surrounding new sources of supply; (4) gaps relating to the need for new forms of planning that can encompass new forms of uncertainty, multiple futures, and the use of greatly expanded new information from models and monitoring stations; (5) gaps and barriers related to the need for better public communication and organizational structures to facilitate cross-agency communication; and (6) knowledge gaps about a number of legal issues relating to changes in timing of water rights, compact issues, water rights administration, the impact of federal environmental laws on state water rights, compliance with NEPA requirements, and federal constraints on the use of model output for planning and operations.

- Options for facilitating adaptation for this sector include the following: (1) CWCB efforts are critical for all water-related climate adaptation. These efforts are funded out of the CWCB Construction Fund through the annual Projects Bill. The governor should recognize the connection between the CWCB Construction Fund, the annual Projects Bill and climate adaptation activities. (2) Adaptation coordination within the Department of Natural Resources (DNR) will require enormous effort given the size and breadth of the department. The governor should set the right tone, as well as commit significant resources if this effort is to succeed. (3) The Statewide Water Supply Initiative (SWSI) process needs to continue, and should explicitly consider climate variability and change. Quantitative studies should be performed whenever possible. Qualitative studies can be useful in all other cases.

Wildlife, Ecosystems, and Forests

- Climate adaptation in this sector is strongly influenced by the activities of the federal resource management agencies, which manage 35 percent of Colorado's land base and share responsibility for managing Colorado's wildlife. Among state agencies, the Colorado Division of Wildlife (DOW) has the most prominent adaptation role in this sector.

- The most serious anticipated impacts of climate change include increasing frequency and severity of forest insect infestations and wildfires (both of which are believed to be occurring already), and changes in the hydrologic cycle that will impact fish and other aquatic organisms. These changes include a reduction in streamflow, a shift to earlier spring runoff, and an increase in stream and lake temperatures.

1. Table 10-1 compiles all sectoral options.

- Most state agencies in this sector are working to explicitly incorporate climate adaptation into their strategic planning and activities, most notably DOW. Several federal resource management agencies have recently released agency-wide strategic plans to adapt to climate change. The adaptation "tool kit" available to resource managers is largely that already used to manage ecosystems for other stressors, employed to increase the "resilience" of ecosystems and species to external change.

- Among the significant barriers to implementing adaptation planning in this sector are (1) the lack of ecological data and models to bridge from climate projections (which are themselves seen as too uncertain) to specific climate impacts on ecosystems, and (2) lack of coordination among the state and federal agencies trying to implement climate adaptation.

- Options for facilitating adaptation for this sector provided by interviewees were (1) promote interagency coordination in adaptation planning and implementation, and (2) continue to build state agency capacity to implement adaptation. Both would be usefully manifested in carrying out other key options: (3) develop the ecological data to bridge from climate projections to climate impacts, (4) conduct a statewide vulnerability assessment for species and ecosystems, and (5) monitor the effects of adaptation strategies that are implemented.

Electricity

- The electricity sector in Colorado is a complex mix of investor-owned utilities, rural electric associations, and municipal utilities. The Public Utilities Commission (PUC) and the Governor's Energy Office are the two primary state-level entities with regulatory and policymaking authority for this sector, although several other state and federal agencies also play important roles.

- Electric utilities in Colorado face a number of climate-sensitive challenges that could be exacerbated by future warming. These challenges include meeting short-term peaks in demand often caused by the need for summertime space cooling; providing water supplies to water-cooled generation units, especially coal-fired power plants; and adapting to impacts of policies and technologies designed to reduce greenhouse gas emissions, including carbon pricing mechanisms and electric vehicles.

- Electric utilities and state agencies already possess significant adaptive capacity through the electric resource planning process, which requires utilities to plan for long-term shifts in demand. Utilities are also accustomed to using a variety of mechanisms to accommodate significant short-term peaks in demand, although current mechanisms are relatively inefficient. Demand response and dynamic metering mechanisms such as the new SmartGridCity offer significant promise for increasing future adaptive capacity in the electricity sector.

- The difficulty of siting new transmission lines to bring renewable power from areas of high potential generation to areas of high demand is a significant barrier currently facing the sector, as is uncertainty about the impact of increased penetration of renewable generation resources.

- Options for facilitating adaptation in the electricity sector include (1) promoting additional research on integrating renewable resources in the grid, (2) giving the PUC a more proactive role in directing utilities to incorporate additional renewables, and (3) tying adaptation and mitigation measures to economic development.

Agriculture

- The agricultural sector is a complex mixture of different production systems spread across Colorado's varied terrains and different climates, involving thousands of individual producers who operate within the changing context of technology, markets, and policy. The dominant policy forces emanate from federal agricultural regulations and support programs. The state plays a supportive role in marketing, extension, federal policy advocacy, research, and data collection, and through programs such as drought response, water and soil conservation, wildlife interactions, and pest management policy.

- Most agricultural production systems rely to some extent on water resources and thus the sector is sensitive to changes in water supply, policy, management, and infrastructure. The sector is further exposed to weather and climate extremes of many types, including extreme heat and cold, winter storms, frost, hail, and flooding, and associated pests and pathogens.

- Despite its exposure to risks, agriculture is widely viewed as particularly adaptable in the face of multiple challenges including climate variability, and the sector in Colorado may be in a position to benefit from some anticipated climate changes, such as warmer conditions and longer growing seasons.

- Barriers to adaptation include market uncertainty at all scales (from local to global), transition costs of changing practices and technology if conditions demand it (including credit and insurance), and increasing competition for water supply.

- Options for the state to facilitate adaptation include mechanisms such as (1) market development; (2) supportive water policy; (3) drought response; (4) research, extension, and technology transfer; (5) insurance and disaster relief; (6) soil and land conservation policy; and (7) provision of climate information and forecasts.

Outdoor Recreation

- The outdoor recreation sector includes a diverse set of government agencies and private actors, although no state agency has overarching regulatory authority over the sector. State Parks manages state-owned recreational resources and has taken the lead on statewide comprehensive outdoor recreation planning. The Division of Wildlife (DOW) manages hunting, fishing, and wildlife viewing in the state. The Colorado Tourism Office promotes Colorado as a tourism destination. The Colorado Water Conservation Board (CWCB) manages instream flows and recreational in-channel diversions, and has studied interactions between water resources and outdoor recreation.

- Climate variability impacts to outdoor recreation identified by interviewees include drought, insect infestations, wildfire, and harm to aquatic species from warmer water temperatures. These impacts could intensify with climate change. Additional climate change impacts of concern include declining snowpack and its effect on water-based recreation, and increased warm weather visitation to the state.

- Most state agencies with a role in outdoor recreation (State Parks, DOW, CWCB) have started incorporating climate change considerations into planning. Certain industries within the outdoor recreation sector, including the ski industry, have adapted to current climate variability to a significant extent.

- Among the most significant barriers to adaptation are lack of data regarding the impacts of climate on recreation; the need to attend to more immediate concerns; lack of coordination across substantive areas; and lack of stakeholder demand to address climate change adaptation in agency strategic planning.

- Options for this sector include (1) compiling and analyzing data on the economic impact of climate on recreation; (2) addressing the impact of increased outdoor recreation and tourism on transportation; and (3) coordinating outdoor recreation adaptation across industries and levels of government.

Key Lessons From Other States

Case studies of climate adaptation planning in Maryland, Alaska, and California are included in this report. This study of the state-of-the-art in state adaptation planning is intended to provide useful guidance for the state of Colorado if it decides to initiate a state adaptation planning effort.

The study found that all three states:

- began with executive or administrative orders by the governor—a strong signal from the chief executive that served to enhance cooperation among state agencies;
- organized their efforts by climate impact or policy-relevant sector working groups;
- included a specific component devoted to adaptation;
- engaged in a stakeholder-driven vulnerability assessment based on expert knowledge of impacted sectors and their policy context;
- identified and focused on the highest priority climate impacts;
- focused on impacts of clear concern to the state and to stakeholders; and
- identified the existing roles and responsibilities of government for each affected resource as well as how to develop adaptation options that were targeted, feasible, and cost-effective.

The differences among the three states were that California's effort was more intragovernmental, with stakeholder input on government-generated work products, while Alaska's and Maryland's efforts were more stakeholder-driven but managed, advised, and reviewed by government officials.

1 Background and Overview

Colorado has always been vulnerable to extreme weather and climate events. Severe winter droughts in 1977 and 1981 pointed out the vulnerability of winter recreation to climate. The ski industry adapted by installing then-novel but now ubiquitous snowmaking equipment. The 1965 floods on the South Platte and Arkansas rivers and the 1976 Big Thompson flood caused significant loss of life and forever changed how the state prepares for and handles flood notifications. More recently, in the midst of a severe drought that peaked in 2002, many Front Range water utilities were forced to impose water use restrictions on residents. During that same summer, the Hayman fire southwest of Denver burned more than 130,000 acres, becoming the largest fire in Colorado's history. Citizens, water providers and the state have adapted by conserving water, stabilizing forests, investigating new sources of supply, and carefully studying how future droughts might occur. Although we cannot be certain of what future climate and weather will bring, we can be certain that normal climate variability and changes in means and increasing extremes due to climate change will continue to challenge Colorado in the 21st century.

In the past the state, localities, and businesses have reduced damages associated with these natural climate events by planning and actions. And planning for climate change is now widely acknowledged to be critical in order to minimize societal impacts.[2] The Colorado Climate Preparedness Project (CCPP) is an effort to summarize current and planned climate adaptation efforts being undertaken by state agencies, their federal counterparts, nonprofit organizations, and private industry as part of planning and policymaking activities. The project is designed to look at both natural climate variability and climate change. Although this is by no means a comprehensive assessment, it is intended to provide the incoming administration with background information to guide future climate adaptation efforts.

2. National Research Council, 2010: America's Climate Choices, Adapting to a Changing Climate. [Available online at www.americasclimatechoices.org/paneladaptation.shtml]

This project was prompted by Governor Ritter's 2007 *Colorado Climate Action Plan: A Strategy to Address Global Warming*. The Climate Action Plan identified three important roles for state government in facing the climate challenge:

> (1) Enact "bridge strategies" that immediately reduce greenhouse gas emissions while we pursue technologies to generate cleaner energy; (2) provide leadership to ensure that long-term solutions, such as renewable energy and clean coal technologies, are fully developed and broadly implemented; and **(3) prepare the state to adapt to those climate changes that cannot be avoided.**[3]

The state has already undertaken efforts to reduce greenhouse gas emissions and support renewable energy.[4] This project examines efforts within Colorado to meet the third goal of the Climate Action Plan—preparing the state to adapt to unavoidable climate changes.

The Colorado Climate Preparedness Project: Scope and Organization

The CCPP was initiated by Governor Ritter and was guided by a team of representatives from the Governor's Energy Office (GEO), Colorado Water Conservation Board (CWCB), Colorado Department of Agriculture (CDA), Colorado Department of Public Health and Environment (CDPHE), Governor's Office, Colorado Department of Natural Resources (DNR), and Colorado Division of Wildlife (DOW). The project was carried out by the CU-NOAA Western Water Assessment.[5] The project focuses on five key sectors that were identified by the state advisory team as particularly sensitive to the impacts of climate variability and change:

- Water
- Wildlife, ecosystems and forests
- Electricity
- Agriculture
- Climate-sensitive tourism and outdoor recreation

In addition, the project examines how decisions and impacts in one sector may affect other sectors.

The CCPP deliverables include a publicly searchable database and this report. The database, located at coloadaptationprofile.org, is a catalog of resources that were selected for their relevance to state-level adaptation planning efforts. It is comprised of four major categories: people, organizations, projects, and products. The database is described in greater detail in chapter 2 and appendix B.

Building on the information included in the database, this report presents the results of the authors' review of adaptation planning throughout Colorado. The chapters that follow focus on each sector's adaptation activities using key documents and information obtained through a series of 22 structured interviews. Relying on the state advisory team's recommendations, we interviewed representatives of key entities in each sector. These included, first, the state agencies with regulatory and/or policymaking authority over their respective sectors. In the water and electricity sectors, our interviews included one major regulated entity. For other sectors we also interviewed organizations with perspectives on the challenges facing decision makers in that sector, such as Rocky Mountain Farmers Union and Colorado State University in the agricultural sector. In the wildlife, ecosystems, and forests sector, federal resource management agencies and NGOs play key roles; thus our interviews included several of those entities.

We also interviewed two organizations that have engaged in climate response efforts across multiple sectors—the Rocky Mountain Climate Organization and the Western Governors' Association—as well as

3. Ritter, 2007: Colorado Climate Action Plan: A Strategy to Address Global Warming (emphasis added).
4. For example, Colorado increased its Renewable Energy Standard from 10 percent to 30 percent by 2020 for Colorado's investor-owned utilities. Further, pursuant to legislation that establishes minimum energy efficiency targets for the state's regulated utilities, all investor-owned gas and electric utilities in Colorado are implementing PUC-approved demand-side management programs. See *Energy Efficiency and Colorado Utilities: How Far We've Come; How Far We Need to Go*, October 20, 2009 [Available online at www.dora.state.co.us/PUC/projects/NewEnergy/PoweringTheFuture/10-20-09NEC_EnergyEfficiency_ColoradoUtilities_PUCreport12-22-09rev.pdf].
5. WWA is a joint effort between the Cooperative Institute for Research in Environmental Sciences at the University of Colorado and the National Oceanic and Atmospheric Administration's Earth System Research Laboratory in Boulder.

the Colorado state climatologist, who tracks observed climate trends. Given time constraints, we did not attempt to comprehensively assess the needs and actions of all stakeholders within a given sector. Table 1-1 lists the interviews by sector, with some interviews listed under multiple sectors.

Table 1-1: List of Interviews Conducted by CCPP Research Team[6]

Agriculture	Electricity	Wildlife, Ecosystems, Forests	Outdoor Recreation	Water	All sectors
Colorado Department of Agriculture (CDA) Rocky Mountain Farmers Union (RMFU) Colorado Water Institute (CWI) CSU Department of Ag and Resource Economics (DARE)	Governor's Energy Office (GEO) Public Utilities Commission (PUC) Xcel Energy (Xcel)	Colorado Department of Natural Resources Executive Director's Office (DNR EDO) Colorado State Forest Service (CSFS) Colorado Division of Wildlife (DOW) U.S. Forest Service White River National Forest (USFS) U.S. Fish and Wildlife Service (USFWS) The Nature Conservancy (TNC) Trout Unlimited (TU)	Colorado State Parks (State Parks) Colorado Division of Wildlife (DOW) U.S. Forest Service White River National Forest (USFS)	Colorado Water Conservation Board (CWCB) Colorado Division of Water Resources (DWR) Colorado Department of Public Health and Environment (CDPHE) Denver Water (Denver Water)	Rocky Mountain Climate Organization (RMCO) Western Governors' Association (WGA) Colorado State Climatologist (State Climatologist)

We asked the interview subjects to identify their organization's top three concerns about the impacts climate variability and climate change will have on their sector, as well as about any existing or anticipated planning for climate variability and change. We also asked about barriers to adaptation. A full set of interview questions is reproduced in appendix A.

The Importance of Climate Adaptation

International and national panels of experts, including the Intergovernmental Panel on Climate Change (IPCC) and the U.S. Global Change Research Program (USGCRP), emphasize the importance of preparing society to adapt to climate variability and change. According to the IPCC, even if global greenhouse gas concentrations were held at 2000 levels, some amount of warming is inevitable, and for some climate change impacts, adaptation is "the only available and appropriate response."[7] The USGCRP Assessment

6. References to the interviews throughout the report use the abbreviated name of each entity, given in parentheses in the table.
7. IPCC, 2007: Summary for Policymakers. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, eds., Cambridge University Press, Cambridge, UK, 7-22, p. 19. [Available online at www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-spm.pdf.]

Report, *Global Climate Change Impacts in the United States*, agrees that adaptation must accompany mitigation efforts to address unavoidable climate change.[8]

Both reports also emphasize the need to address barriers to adaptation. The IPCC cautions that there are "formidable environmental, economic, informational, social, attitudinal and behavioral barriers to the implementation of adaptation."[9] In addition, the USGCRP Assessment Report warns that

> Humans have adapted to changing climatic conditions in the past, but in the future, adaptations will be particularly challenging because society won't be adapting to a new steady state but rather to a rapidly moving target. Climate will be continually changing, moving at a relatively rapid rate, outside the range to which society has adapted in the past. The precise amounts and timing of these changes will not be known with certainty.[10]

Climate change adaptation has received a great deal of attention at the federal level. Many of those efforts are described in the Pew report, *Climate Change Adaptation: What Federal Agencies are Doing*,[11] as well as throughout this report where relevant. President Obama issued an executive order in October 2009 requiring the Interagency Climate Change Adaptation Task Force to assess federal government climate change adaptation activities and to provide recommendations for additional actions to support a national adaptation strategy. The Task Force's initial findings and recommendations were released in early October 2010.[12]

In response to a congressional request, the National Research Council convened a panel to examine the country's choices in adapting to climate change and issued a report, *Adapting to the Impacts of Climate Change*.[13] Among other recommendations, the report urged that states initiate adaptation planning and implementation regardless of whether the federal government takes a leadership role, and take a significant leadership and coordination role especially where cities and other local interests have not yet established adaptation efforts. The panel also recommended specific provisions that should be included in state adaptation plans.

A Brief History of Efforts to Support Statewide Adaptation in Colorado

The CCPP builds on previous state-level efforts, beginning over ten years ago with the 1998 CDPHE report, *Colorado and Climate Change: A Technical Assessment*.[14] While adaptation is mentioned, the 1998 report focused on greenhouse gas mitigation measures. The greenhouse gas emissions inventory included in the report was revised in 2000[15] and again in 2002.[16]

The Rocky Mountain Climate Organization (RMCO) initiated the Colorado Climate Project in 2005 to "bring Coloradans together to reduce the state's contribution and vulnerability to climate change."[17] The project was modeled after state government efforts, in particular, those in Arizona, New Mexico, and Montana. Unlike those other efforts, the Colorado Climate Project was undertaken by a non-profit organization rather than state government. The project's 116-member Climate Action Panel developed 70 mitigation and adaptation recommendations, many of which were incorporated into the Governor's

8. Karl, T R., J M. Melillo, and T. C. Peterson, eds., 2009: *Global Climate Change Impacts in the United States*. Cambridge University Press, p. 11. [Available online at downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf.]
9. Climate Change 2007: Impacts, Adaptation and Vulnerability, p. 19
10. Global Climate Change Impacts in the United States, p. 11
11. *Climate Change Adaptation: What Federal Agencies are Doing*. A Report by the Pew Center on Global Climate Change, November 2010.
12. The White House Council on Environmental Quality, 2010: *The Progress Report of the Interagency Climate Change Adaptation Task Force: Recommended Actions in Support of a National Climate Change Adaptation Strategy*, October 5. [Available online at www.whitehouse.gov/sites/default/files/microsites/ceq/Interagency-Climate-Change-Adaptation-Progress-Report.pdf.]
13. America's Climate Choices website. [Available online at www.americasclimatechoices.org/paneladaptation.shtml, accessed November 21, 2010.]
14. Woodford, P., F. Quarterone, W.W. Berg, and J.C. Erickson, 1998: *Climate Change and Colorado: A Technical Assessment*. Colorado Dept. of Public Health and Environment, prepared under a grant from the EPA's climate change program. [Available online at www.cdphe.state.co.us/climate/climatechange.pdf.]
15. [Available online at www.cdphe.state.co.us/climate/climateupdate.pdf]
16. [Available online at www.cdphe.state.co.us/climate/greenhouse.pdf]
17. Colorado Climate Project website. [Available online at www.coloradoclimate.org, accessed November 18, 2010.]

Climate Action Plan.[18] RMCO is currently encouraging the implementation of its recommendations through several initiatives.[19] In addition, an updated greenhouse gas inventory and projections were developed as part of the project.[20]

Governor Ritter's 2007 Climate Action Plan directed the Department of Natural Resources (DNR) and Public Health and Environment (CDPHE), in collaboration with others, to develop a water adaptation plan that would include 1) scientific investigation, 2) analysis of water rights and compacts, 3) comprehensive drought planning, and 4) information exchange and education. The CAP also directed the DNR, CDPHE and Governor's Energy Office (GEO) to reduce the risk of catastrophic wildlife, promote forest-based biofuels, and otherwise anticipate and respond to potential adverse climate change impacts on forests.

In 2008, the CU-NOAA Western Water Assessment developed a report for the Colorado Water Conservation Board, *Climate Change in Colorado, A Synthesis to Support Water Resource Management and Adaptation*, which assembled the findings of climate science relevant to Colorado's water supply.[21] Key findings from this report include the following:

- Temperatures have increased by approximately 2°F in Colorado between 1977 and 2006
- There was little change in annual precipitation during this period
- Climate models project that Colorado temperatures will increase by 2.5°F in 2025 and 4°F by 2050 relative to a 1950-99 baseline
- Summers are projected to warm more than winters
- Climate models do not agree on whether it will get wetter or drier by 2050
- Between 1978 and 2004 runoff timing shifted earlier by two weeks
- Multi-model average reductions for the Colorado River runoff range from -6 to -20 percent by 2050[22]

Additional efforts have been completed or are underway, and will be described in further detail throughout this report.

Governor Ritter issued an executive order[23] creating a Climate Change Advisory Panel in 2009. The panel, which includes 30 members representing industry, academia, government, law and other sectors, was charged with examining mechanisms for conducting effective planning for climate change adaptation.[24]

The Denver-based Western Governors' Association (WGA), a nonpartisan organization serving the needs of the governors of the 19 western states, is also actively supporting state-level climate change adaptation planning. Following issuance of Policy Resolution 09-2 in 2009, which states in part that "Western Governors believe that planning for climate change adaptation should be undertaken in a coordinated fashion at all levels of government with state expertise being fully utilized,"[25] WGA created a Climate Adaptation Work Group (CAWG). The CAWG scoping report identifies state and regional priorities

18. Colorado Climate Project, 2007: *Final Report of the Climate Action Panel*. Rocky Mountain Climate Organization, November. [Available online at www.coloradoclimate.org/Climate_Action_Panel.cfm.]
19. [Available online at www.rockymountainclimate.org/programs_3.htm]
20. *Final Colorado Greenhouse Gas Inventory and Reference Case Projections, 1990–2020*, prepared by the Center for Climate Strategies for the Climate Action Panel of the Colorado Climate Project, October 2007.
21. Ray, A.J., J.J. Barsugli, K.B. Averyt, 2008: *Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation*. A report by the Western Water Assessment for the Colorado Water Conservation Board. [Available online at www.cwcb.state.co.us/public-information/publications/Documents/ReportsStudies/ClimateChangeReportFull.pdf, accessed December 1, 2010.]
22. The report's Executive Summary is reproduced in full in appendix C.
23. Executive Order B 007 08
24. June 22, 2009 press release, [Available online at www.colorado.gov/cs/Satellite?c=Page&cid=1245677988060&pagename=GovRitter%2FGOVRLayout.]
25. [Available online at www.westgov.org/index.php?option=com_wga&view=resolutions&Itemid=53]

for planning and adapting to climate change. [26] The report reinforced messages that emerged from the Climate Action Plan regarding the importance of state adaptation action:

> Existing state and regional institutions form the core of climate response in the West. Many climate adaptation decisions can now be made using existing institutions and authorities. The states should seek to identify potential barriers to climate adaptation and ensure that their agencies, legal and regulatory frameworks, and institutions provide sufficient flexibility to address potential climate change impacts. To the extent practicable, Governors should encourage state agencies to plan for, and begin to integrate climate considerations into, decision making.[27]

The CCPP provides a bridge between these efforts and ongoing state actions in Colorado aimed at climate adaptation.

This report and the associated database are intended to provide baseline information to facilitate the continuation of state climate adaptation planning and implementation. This chapter provides an overall introduction to the CCPP and a very broad historical overview of state activities. Chapter 2 describes the database. Chapters 3-7 describe potential vulnerabilities and ongoing and planned adaptation efforts in each of the five sectors studied for this report: water; wildlife, ecosystems and forests; electricity; agriculture; and climate sensitive tourism and outdoor recreation. Chapter 8 synthesizes lessons learned from climate change adaptation efforts in selected states. Chapter 9 summarizes cross-sectoral impacts. Chapter 10 synthesizes the chapters and provides options and recommendations for further planning. The appendix includes the interview questions, instructions for using the database, and additional climate resources. A list of literature cited in this report is available in the database (see chapter 2) under "Products." It is titled "Colorado Climate Preparedness Project Final Report List of Literature Cited."

26. Western Governors' Association, 2010: Climate Adaptation Priorities for the Western States: Scoping Report, Denver. [Available online at www.westgov.org/index.php?option=com_wga&view=reports&Itemid=54.]
27. Id. at 6-7

2
Database and Wiki

The Colorado Climate Preparedness Project database (www.coloadaptationprofile.org), one of the two deliverables of this project, provides a searchable, linked compilation of organizations, people, projects and products related to state adaptation efforts.

The project team has populated the database with information from the interview process and relevant documents. The database also contains a wiki component[1] that will allow registered users—individuals who have already been entered in the "People" section of the database and who choose to take advantage of the wiki's full functionality—to edit existing content and add new content.[2] Such users can add new products, projects, or organizations linked to their entry in the "People" section, as well as highlight and comment on other elements throughout the site. This will allow the wiki and database to evolve to meet user needs.

The four linked sections are described below and their relationships illustrated in figure 2-1:

1. **Organizations:** Entities actively involved in climate adaptation. These include NGOs with a specific climate change mission such as the Rocky Mountain Climate Organization, groups of elected officials with a broader mission but which have addressed climate change such as the Western Governors' Association, university programs that are relevant to one of the sectors in this project such as CSU's Colorado Climate Center, and consulting firms that have authored major reports.

2. **People:** Authors of key reports and plans as well as personnel within government agencies, NGOs, consulting firms, and academia identified by the project team as having expertise relevant to climate adaptation efforts.

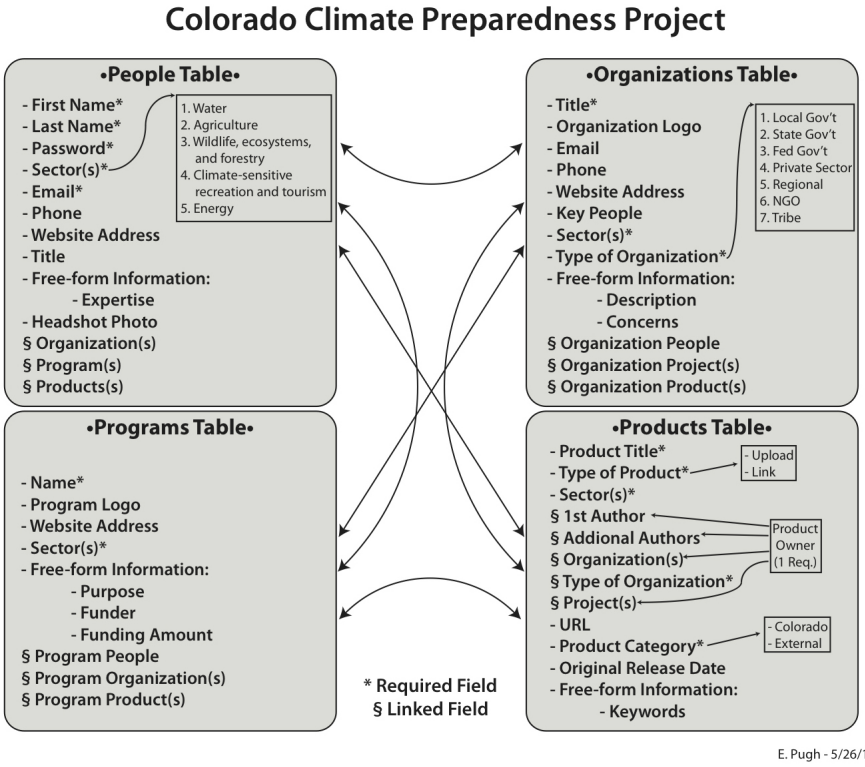
3. **Projects:** Programs within larger organizations with a climate adaptation connection, such as the Rocky Mountain Climate Organization's Colorado Climate Project and the city of Aspen's Canary Initiative.

4. **Products:** Reports, studies, websites, major meetings and other relevant material outputs. In addition to climate change adaptation plans and studies, we have included selected natural hazard mitigation plans which can serve as a resource for climate adaptation planning by illustrating measures

1. A wiki is a collaborative website that can be directly edited by anyone with access to it.
2. Instructions for using the database are in appendix B.

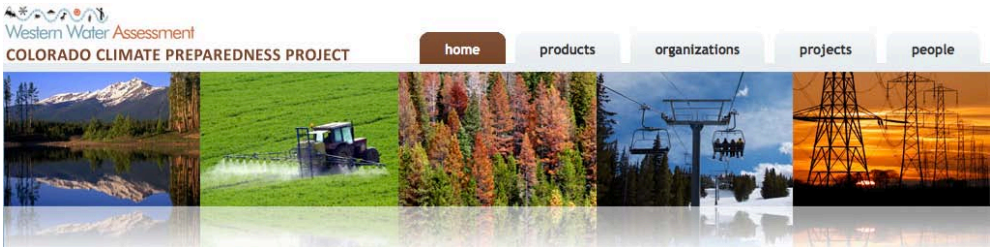
already in place to adapt to climate variability. Assessments such as the *Colorado Statewide Forest Resource Assessment* are included because of their discussion about climate impacts on one of the sectors in the project. Reports such as *Colorado's Comprehensive Wildlife Conservation Strategy and Colorado's Statewide Comprehensive Outdoor Recreation Plan (SCORP)* illustrate state agency recognition of the impact of climate on resources and efforts to integrate climate change response into state agency strategic thinking.

Figure 2-1: Structure of Database



From the home page one can navigate to all four sections through a set of tabs at the top of the site. Each tab opens to an alphabetical list of entries, which can be browsed, searched and sorted according to the needs of the user.

Figure 2-2: Home Page



"Products" and "Organizations" can be sorted by sector, type of author (local, state, or federal government; private sector; regional; NGO; tribe; academic/university), and whether the product was produced in Colorado or elsewhere. "Projects" can be sorted by sector and whether the project is located in Colorado or elsewhere. "People" can be sorted by whether or not an individual is a Colorado state employee. Searches are independent of browsing, and can be made in various combinations of keywords, summary, purpose, description and name. Users can also download reports, studies and other relevant material in the "Products" section.

After the name and a brief description, organizations are categorized and assigned to one or more sectors. Any organizational concerns are followed by contact information tailored to be as specific to Colorado as possible. Finally, any projects, people, or products associated with the organization are contained in linked fields, which can be used to navigate to their respective entries elsewhere within the database. Project, product, and people entries follow similar templates.

Additional information about browsing and searching the database is included in appendix B.

3 Water Sector in Colorado

Key Points

- Among state agencies, the Colorado Water Conservation Board (CWCB) has the most prominent adaptation role in this sector.
- The most serious anticipated impacts of climate change include shifts in timing and intensity of streamflows and runoff, reductions in late-summer flows, decreases in runoff, increases in drought, and modest declines for Colorado's high-elevation snowpack.
- Most state agencies in this sector are working to explicitly incorporate climate adaptation into their strategic planning and activities, most notably CWCB.
- Among the significant barriers to implementing adaptation planning in this sector are (1) gaps in climate and hydrology monitoring; (2) gaps in hydrology and climate-related research on changes in extreme events, demands, runoff, and groundwater-surface water interactions; (3) gaps surrounding new sources of supply; (4) gaps relating to the need for new forms of planning that can encompass new forms of uncertainty, multiple futures, and the use of greatly expanded new information from models and monitoring stations; (5) gaps and barriers related to the need for better public communication and organizational structures to facilitate cross-agency communication; and (6) knowledge gaps about a number of legal issues relating to changes in timing of water rights, compact issues, water rights administration, the impact of federal environmental laws on state water rights, compliance with NEPA requirements, and federal constraints on the use of model output for planning and operations.
- Options for facilitating adaptation for this sector include the following: (1) CWCB efforts are critical for all water-related climate adaptation. These efforts are funded out of the CWCB Construction

Fund through the annual Projects Bill. The governor should recognize the connection between the CWCB Construction Fund, the annual Projects Bill and climate adaptation activities. (2) Adaptation coordination within DNR will require enormous effort given the size and breadth of the department. The governor should set the right tone, as well as commit significant resources if this effort is to succeed. (3) The SWSI process needs to continue, and should explicitly consider climate variability and change. Quantitative studies should be performed whenever possible. Qualitative studies can be useful in all other cases.

Overview

This chapter discusses climate preparedness as it pertains to water. Colorado's water sector is enormously complicated with numerous state, regional, local, and NGO actors and many differing points of view influenced by geography (Great Plains versus mountains), end point of use (agricultural versus municipal), and how water is used (environmental and recreational non-consumptive uses versus all consumptive uses). Water availability impacts many other sectors such as agriculture, outdoor recreation, power production and the environment. This chapter focuses on state activities to adapt to climate variability and change in the realm of water supply, water demand, and water quality. It also briefly discusses some of the climate-related activities of major Front Range water providers. Other chapters in this report discuss cross-sectoral impacts of water, such as the relationship between agriculture and water, or recreation and water.

The chapter begins by describing sources of information and then provides a brief overview of water in the state including physical supply, demands, infrastructure, allocation, legal issues and key state agencies. Potential climate change impacts to water both globally and locally are covered next. Climate adaptation activities recently completed, underway, and planned are the heart of the chapter. The section concludes with barriers and gaps to adaptation with associated options, and finishes with a final section on overarching recommendations.

Sources Used to Prepare Report

The information in this section was drawn from interviews with the Colorado Water Conservation Board (CWCB), the Colorado Division of Water Resources (DWR, also known as the state engineer's office), and the Colorado Department of Public Health and Environment (CDPHE). One major non-state actor, Denver Water, the largest water provider in the state, was interviewed at the request of the CCPP state advisory team. In addition to the interviews, the CCPP performed a literature search. Relevant information from publicly available federal, state, and other sources was obtained and is cited as necessary. The vast majority of stakeholders in the water sector were not interviewed and their climate-related activities are not presented in this document, but many of their climate adaptation activities can be found in the accompanying CCPP database.

Climate information was primarily obtained from the water sector chapter of the recently released *Global Climate Changes Impacts on the United States*,[1] a 2009 publication of the U.S. Global Change Research Program (USGCRP), and from the Colorado Water Conservation Board's 2008 *Colorado Climate Report: A Synthesis to Support Water Management*.[2] The Intergovernmental Panel on Climate Change (IPCC) *Technical Paper on Water*[3] and two other recent USGCRP reports, the *Effects of Climate Change*

1. Karl, T. R., J. M. Melillo, and T. C. Peterson, eds., Global Climate Change Impacts in the United States, 2009: Cambridge University Press. [Available online at www.globalchange.gov/publications/reports/scientific-assessments/us-impacts.]
2. Ray, A.J., J.J. Barsugli, K.B. Averyt, 2008: *Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation.* A report by the Western Water Assessment for the Colorado Water Conservation Board. [Available online at www.cwcb.state.co.us/environment/climate-change/Documents/COClimateReportOnePager.pdf, accessed December 16, 2010.]
3. Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, eds., 2008: Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva, 210 pp.

on Agriculture, Land Resources, Water Resources and Biodiversity in the United States[4] and *Weather and Climate Extremes in a Changing Climate*, were also used.[5]

A Short Overview of Water in the State

Physical Supply and Use

Colorado is commonly called the Headwaters State because it contains the headwaters of numerous western rivers including the Colorado, Rio Grande, Arkansas, South Platte, North Platte, and San Juan rivers. The Continental Divide splits Colorado and hence the state's East Slope rivers flow to the Atlantic Ocean and the West Slope drains to the Pacific Ocean. With one exception all of Colorado's rivers originate within the state, a relatively unusual occurrence among the 50 states.[6]

Colorado's water supplies are extremely variable from year to year and from season to season. Colorado River flows measured at Lees Ferry in Arizona can vary, for example, by up to a factor of five from extreme drought to extreme wet years. Four-hundred-year tree-ring studies of the Blue River below Dillon Reservoir show that flows can vary by a factor of almost four from year to year. Almost all of Colorado's rivers are snowmelt driven with large quantities of water flowing in the spring which later dwindles to a trickle in the fall. Water management was originally directed at smoothing out these seasonal and annual fluctuations so that agricultural, municipal and industrial users could have access to a more dependable water supply.

Water in Colorado is used for both consumptive uses (e.g., agriculture, municipal outdoor, power plant cooling) and non-consumptive uses (e.g., municipal indoor[7], recreational, environmental). Historically water management was primarily concerned with consumptive uses, but in recent years non-consumptive uses have developed strong support from several important recreational sectors and from environmental organizations. Agriculture accounts for approximately 80 percent of all water consumed in the state (approximately five million acre-feet (MAF) per year is used on 3.5 million irrigated acres) while the state's five million citizens use the remaining 20 percent (one MAF) for municipal and industrial uses.

A defining physical feature of the state's water is that approximately 80 percent of the supply is on the West Slope, while 80 percent of the demand on the East Slope. This fact has led to significant infrastructure investments to move water from west to east. It also strongly influences policy as east–west divisions occur frequently.

Recent state studies and initiatives project that the state's population will grow from 60 percent (to eight million total) to 100 percent (to 10 million total) by 2050.[8] These efforts are designed to investigate how this growth can best be accommodated with the least amount of impacts using three primary techniques: (1) conservation and efficiency, (2) transfers from agriculture, and (3) new water storage and delivery infrastructure development.

4. CCSP, 2008: *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity.* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Backlund, P., A. Janetos, D. Schimel, J. Hatfield, K. Boote, P. Fay, L. Hahn, C. Izaurralde, B.A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson, D. Wolfe, M. Ryan, S. Archer, R. Birdsey, C. Dahm, L. Heath, J. Hicke, D. Hollinger, T. Huxman, G. Okin, R. Oren, J. Randerson, W. Schlesinger, D. Lettenmaier, D. Major, L. Poff, S. Running, L. Hansen, D. Inouye, B.P. Kelly, L Meyerson, B. Peterson, R. Shaw. U.S. Environmental Protection Agency, Washington, DC., USA, 362 pp.
5. CCSP, 2008: Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. T. R. Karl, G. A. Meehl, C. D. Miller, S. J. Hassol, A. M. Waple, and W. L. Murray, eds. Department of Commerce, NOAA's National Climatic Data Center, Washington, D.C., USA, 164 pp.
6. The Green River with headwaters in Wyoming's Wind River Mountains flows briefly into and out of the state in the northwest flowing through Dinosaur National Park.
7. Unlike recreational and environmental uses, municipal uses divert water from a stream. However, almost all indoor use is returned to the stream via sewage treatment plants and hence in some settings may be termed non-consumptive.
8. cwcbweblink.state.co.us/weblink/0/doc/144800/Electronic.aspx?searchid=c1469548-e589-49df-a54f-6b03612a38e3

Infrastructure

Reservoirs are the primary tools used by water managers to handle both seasonal and year-to-year variability in flow. The original Colorado reservoirs were small agricultural facilities designed to capture the spring flush so that it could be used later in the same year. In later years, larger reservoirs with the capacity to store water over several years (e.g., Dillon, Green Mountain, Blue Mesa, John Martin) allowed water managers to handle the substantial year-to-year variability in flow. The total water storage capacity of the 75 largest reservoirs in Colorado exceeds six MAF[9]; there are approximately 3000 smaller reservoirs throughout the state.[10]

In addition to many large and small reservoirs, the state contains other major water infrastructure including irrigation canals, transmountain tunnels (e.g., Adams and Roberts), pumping stations, raw water treatment plants, and wastewater treatment plants. Collectively, this infrastructure is critical for water management, would cost many billions of dollars to replace, and can be seriously impacted by weather and climate. For example, recent fires in the South Platte have caused Denver Water to spend millions of dollars dredging Strontia Springs Reservoir of sediment.

Water Allocation

Determining who gets what water and when is a significant responsibility of the state. Colorado's surface water and tributary groundwater is allocated based on the Prior Appropriation Doctrine using the premise of "first in time, first in right." The Colorado Water Court, a special division of Colorado's court system, adjudicates all water rights in the state, including most groundwater.[11] In Colorado, water rights can be obtained for "beneficial uses," a term that originally applied only to consumptive uses for such purposes as mining, agriculture, and domestic needs. Colorado was among the first states to acknowledge that non-consumptive uses were important, and in 1973 the legislature created instream flow rights to preserve the natural environment to a reasonable degree; the Colorado Water Conservation Board (see below) holds these rights. In 2001 the Colorado General Assembly authorized local governmental entities to obtain a new form of non-consumptive water right for recreational activities, such as kayak water parks. In addition to the state's water rights system, all of the state's rivers are subject to numerous complicated interstate compacts and U.S. Supreme Court decrees, which apportion water among states.[12] Contrary to common public perception, Colorado does not have the right to use all the water that originates in the state and must deliver significant quantities downstream under these compacts and decrees.

State Agencies with Major Water Responsibilities

In Colorado, there are two major state departments with responsibility over water resources, the Colorado Department of Natural Resources (DNR) and the Colorado Department of Public Health and Environment (CDPHE). The DNR is the home of two water related agencies, the Division of Water Resources (DWR), and the Colorado Water Conservation Board (CWCB). The DWR oversees administration of rights associated with surface and groundwater and is the home of the state engineer. The CWCB responsibilities include aiding in the protection and development of state water resources for present and future generations, gathering data and information to achieve greater utilization of the water of the state, and identifying and recommending water development projects to the General Assembly.

The second major state department with responsibility for water, the Colorado Department of Public Health and Environment (CDPHE), ensures compliance with federal and state water quality standards (e.g., Clean Water Act, Safe Drinking Water Act), and manages permitting for sources of pollution, among many other responsibilities.

9. The NRCS keeps track of the largest reservoirs at: www.wcc.nrcs.usda.gov/ftpref/data/water/basin_reports/colorado/wy2011/barsco10.txt.
10. See www.lat-long.com/ListLocations-1-Colorado-Reservoir.html.
11. A special form of groundwater, 'designated groundwater', is handled by the Colorado Groundwater Commission, not the Water Court.
12. For a discussion of these agreements see water.state.co.us/surfacewater/compacts/Pages/default.aspx or cwcb.state.co.us/legal/Documents/InterstateCompacts/CompactFacts.pdf.

Table 3-1: Characteristics of the Major State of Colorado Water Agencies

State Agency	Decision Making Authority	Strategic Planning	Role in the State
Colorado Division of Water Resources	• State engineer reports to the executive director of the Department of Natural Resources	• No state water plan • No specific climate plan	• Water administration of surface and groundwater, public safety (dams, water wells), • Compact administration • Regulatory
Colorado Water Conservation Board	• 15- member board: voting members appointed by governor, confirmed by state senate • Members represent basins, including metro region • Board makes policy decisions, staff prepares recommendations in advance • CWCB director reports to the board and the executive director of the Department of Natural Resources	• 2006 strategic plan in place, currently being revised • Current plan does not explicitly mention climate or climate change, although climate is clearly implicit in all CWCB activities.	• Provides information, technical resources and financial support for local entities as well as facilitation for statewide planning • Policy making
Colorado Department of Public Health and Environment	• Nine -member commission sets regulatory framework for ensuring water quality is maintained or, where impaired, restored	• CDPHE strategic plan and a strategic plan for water quality • Specific climate change component to plan	• Implements federal and state waste water permitting program • Oversees compliance with Clean Water Act • Regulatory

Potential Climate Change Impacts to the Water Cycle and Colorado's Water Supplies

The planet's water cycle is the primary mechanism by which the Earth moves heat from areas of too much, such as the equator, to areas of too little, such as the poles. It is this movement of warm water from the equator, in the form of water vapor and large ocean currents like the Gulf Stream, that creates weather and climate. Under a warmer climate, the physics of the atmosphere fundamentally change with the water-holding content of the atmosphere increasing by approximately 4 percent per degree F warming. On a global basis both evaporation and precipitation are expected to increase significantly in a warmer world, but there will be distinct regional winners and losers with "wet areas getting wetter and dry areas getting drier."

In the future with additional warming affecting the basic physics of the atmosphere, with increased global evaporation and precipitation, and with differential heating (the poles are heating approximately twice as fast as elsewhere), the water cycle is expected to change significantly. This critical finding, known for many years by the scientific community, is supported by climate theory, by climate models, and by recent observations.

With respect to future changes in the water cycle, the 2009 *Global Climate Change Impacts in the United States* report found that

- climate change has already altered and will continue to alter the water cycle affecting where, when, and how much water is available;
- floods and droughts are likely to become more common and more intense as regional and seasonal patterns change;
- precipitation and runoff are likely to decrease in the West, especially the Southwest, in spring and summer;
- in areas of snowpack, the timing of the runoff will continue to shift to earlier in the spring and flows will be lower in late summer;
- climate change will place additional burdens on already stressed water systems; and
- the past century is no longer a guide to the future for water management.

In 2008 the Colorado Water Conservation Board released the *Climate Change in Colorado* report. The report contained six chapters: (1) an introduction, (2) a look at trends in historical data, (3) a climate model primer, (4) a look at the attribution of recent climate changes, (5) climate projections and (6) a brief discussion of the implications of the findings. The executive summary contained numerous significant conclusions, all of which are reproduced in appendix C.

Although the report was designed primarily to discuss scientific findings similar to the report of the Intergovernmental Panel on Climate Change Working Group I, the final chapter had a brief discussion of the potential societal and environmental impacts of the science. Table 3-2 lists the 10 key implications which range from water demands to water infrastructure; law; water quality; energy impacts; mountain habitats; interplay among forests, hydrology, wildfires and pests; riparian habitats and fisheries; and water and snow-based recreation. The CWCB Board requested and received funding from the legislature for a follow-on 2010 report further identifying these key water system impacts and vulnerabilities but this phase has been delayed.

Table 3-2: Key Implications from *Climate Change in Colorado*

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 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 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.

Current and Planned Adaptation Activities

Overview of Adaptation

Minimizing the effects of natural climate variability was a fundamental reason for the establishment of modern water management in the early 20th century. Throughout the last century historical precipitation and runoff records were used as the basis for most water-related planning decisions and water managers became adept at balancing supplies and demand using this information. However, because of the strong connection between global warming and the water cycle, these past records will be less and less valuable for planning in the 21st century. This concept is frequently expressed as "climate stationarity is dead", meaning that the past is no longer a guide to the future.[13] Planning for an uncertain future presents a new challenge for water managers and many of the water-related adaptation efforts underway around the world are directed at solving this problem.

13. Milly, C., et al., 2008: Stationarity is Dead: Whither Water Management. Science, 319, 573-574.

Although scientists have long had conferences and written papers about climate change (the first study on the Colorado River was performed in 1983), water managers have only recently begun to consider the issue in their planning efforts. A seminal moment for water managers occurred in January 2007 when the San Francisco Public Utilities Commission held a national climate change summit for water utilities. The Water Utility Climate Alliance, of which Denver Water is a founding member, was established at that event by eight of the largest water utilities in the country. It is worth noting that, while much has transpired in the water management community with respect to climate change adaptation since 2007, these efforts are less than four years old.

Adaptation Activities in Colorado

Colorado has always been active in planning for water at the state, regional, and local levels. The CWCB was established more than 75 years ago to help provide water policy and planning for the state. Project-based planning was, however, left to the water delivery entities and the state did not have a statewide planning effort until 2003.

Large population growth in the 1990s along with the 2000s drought encouraged additional focus on planning. In 2003 the legislature directed the CWCB to perform the first statewide planning effort, the Statewide Water Supply Initiative (SWSI). The first phase of SWSI was accomplished in a short 18 months. The effort focused on future demands and identified major gaps in water supply planning by 2030. The Interbasin Compact Committee (IBCC) and nine official Basin Roundtables (BRTs) were established by the legislature's Water for the 21st Century Act in 2005. As climate change science has progressed, and as SWSI, the IBCC and the BRTs have matured, climate change discussions are being integrated into the state's water supply planning.

The state adaptation activities listed below vary in their connection to climate variability and climate change. Some support climate adaptation activities such as data collection (stream gaging, water rights tabulation, precipitation frequency maps, snowmelt and runoff timing study); some support education (workshops, reports and conferences); some support statewide planning (Colorado's Drought Mitigation and Response Plan, SWSI), some consider the connection between sectors (water-energy); some are focused primarily on climate variability (drought plans, Colorado River Compact Compliance study); some attempt to increase supplies (weather modification); and some are expressly focused on climate change (Colorado River Water Availability Study, Colorado River Basin Study). Over the last three years there has been a strong move to incorporate climate change into most studies on water at CWCB, even when the scientific and engineering means to do so are not clear. Additional information on the projects discussed below is available in the accompanying database.

Stream Gage Monitoring, Online Water Rights Tabulation

Colorado is the only western state with its own hydrographic monitoring system.[14] The system primarily is managed by the Division of Water Resources and is currently used to monitor, enforce and administer both consumptive and non-consumptive water rights, including instream flows. The DWR also invested in a new portal that allows for public searches of the state water rights database.[15] The CWCB, the Division of Water Resources, the U.S. Geological Survey (USGS) and numerous water users cooperate on funding and performing the installation, operation and maintenance of stream gages in Colorado. Data is critical to both science and management; without data there can be no science, and without data, management is extremely challenging.

Precipitation Frequency Maps

The CWCB is collaborating with NOAA to develop a suite of historic and projected precipitation frequency maps for the Colorado region. The analysis, to be completed in early 2012, will provide information on locations where precipitation frequency and intensity are changing. These maps are important for

14. www.dwr.state.co.us/Surfacewater/default.aspx
15. www.dwr.state.co.us/WellPermitSearch/default.aspx

a variety of planning purposes including flood calculations. Climate change science has consistently predicted that future storms will be more intense and hence the return period of a given size flood event will decrease. These maps will help the state begin to characterize the changing flood risk.

Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation

In October 2008, the CWCB released the *Climate Change in Colorado* report. This report was peer-reviewed by a wide variety of people including scientists, engineers, water professionals from the major state universities, the National Center for Atmospheric Research, various consultants, and water managers of all stripes. It is discussed above in the Climate Impacts section of this chapter. When it was completed a future Phase 2 report similar to the IPCC Working Group II report on impacts, adaptation and vulnerabilities was envisioned and CWCB later obtained legislative funding for this effort in 2010. Phase 2 was subsequently put on hold.

Statewide Water Supply Initiative

In 2003 the legislature directed the CWCB to coordinate a statewide study of future water needs in every basin in the state.[16] Never before had such a large, all-encompassing, planning initiative been undertaken, and initially there was some resistance from local water providers to what was viewed as a local and regional prerogative. This initiative, the Statewide Water Supply Initiative (SWSI), created Basin Roundtables throughout the state to provide grassroots stakeholder input into the process. In late 2004 the SWSI report was released.[17] It analyzed basin-by-basin the future water needs, what was being done to address those needs, what areas were short of water and by how much, and what was being done about the shortfall. It did not include climate variability and change. Major findings are presented in box 3-1.

BOX 3-1: 2004 SWSI Major Findings

SWSI produced eight major findings: (1) population growth will intensify competition for water. (2) Local projects would be able to fill 80 percent of the need at 2030. (3) To the extent that these projects were not successful, agricultural land dry-up would be a concern. (4) Supplies are not where demands are. (5) Reliance on non-renewable water sources in some areas is a large concern. (6) Water conservation will be a major tool but cannot be the entire solution. (7) Environmental and recreational uses are growing and will conflict with existing uses. (8) Little planning has been done beyond 2030. (From Page ES-7).

In 2007, a Phase 2 technical update of SWSI was performed. This report focused on water conservation and efficiency and alternative agricultural water transfer methods, delineated Colorado's environmental and recreational resources and needs, and addressed the municipal and industrial water supply gap between current and future needs. For the most part the report did not integrate either climate variability or climate change into the analysis other than acknowledging the need to take climate variability into account when evaluating future conservation.

In 2010 further SWSI updates were undertaken. A draft report on the current and 2050 agricultural demands has been released.[18] This report included a qualitative description of climate change impacts on agricultural demands, but did not make quantitative estimates of climate change impacts on crop demands. The municipal and industrial water use projections to 2050 report has been finalized.[19] This analysis did not include climate change in the demand projections; however, the possible influence of

16. Statewide water planning is now performed in roughly 30 states. California is legislatively mandated to produce plans every five years. See www.waterplan.water.ca.gov/. As of 2005, only eight percent of the plans included climate change. See email.asce.org/ewri/StateWater.html.
17. [Available online at cwcb.state.co.us/public-information/publications/Pages/StudiesReports.aspx.]
18. CDM, 2010: State of Colorado Current and 2050 Agricultural Demands. July 27. [Available online at cwcbweblink.state.co.us/WebLink/ElectronicFile.aspx?docid=144104&searchid=bf933fd3-936d-4ee8-b767-4e617f8e3286&dbid=0.]
19. CDM, 2010: State of Colorado 2050 Municipal and Industrial Water Demands. July. [Available online at cwcbweblink.state.co.us/weblink/0/doc/144800/Electronic.aspx?searchid=c1469548-e589-49df-a54f-6b03612a38e3.]

climate change on population projections was analyzed. Because the impacts of climate change were not quantified in the M&I demand forecasts, they were not included in the M&I gap analysis report which was also recently released.[20] The Municipal and Industrial Water Conservation strategies draft report was released in November 2010.[21] This report stated that climate change was not incorporated in these estimates, but is important and should be a part of future updates. Finally, a reconnaissance-level report on new project costs requested by the IBCC did not include any discussion about how climate change might impact those costs.[22]

Colorado Drought Mitigation and Response Plan

State-level drought planning is mandated under federal natural hazard mitigation planning laws and regulations, and in Colorado the drought plan is prepared by CWCB in cooperation with the Department of Local Affairs Division of Emergency Management. In 1981 Colorado was one of the first states to craft a drought plan following a severe drought. The plan was updated in 1986, 1990, 2001, and 2007.[23] In 2010, the plan was comprehensively revised and is officially known as the Colorado Drought Mitigation and Response Plan. Annex C of the drought plan utilized results from the Colorado River Water Availability Study to investigate how future droughts might change under climate change conditions. Previous local efforts from the city of Boulder were also incorporated. In general, future droughts may be more severe than past droughts.

Colorado Flood Hazard Mitigation Plan

Flood planning, like drought planning, is mandated under federal natural hazard mitigation planning laws and in Colorado flood plans are prepared by CWCB in cooperation with the Department of Local Affairs Division of Emergency Management. The original Colorado flood plan was prepared by CWCB following the Lawn Lake flood in 1982 and was updated in 2004 and 2007.[24] In 2010, the plan was comprehensively revised. The current version of the plan does not specifically incorporate climate change.

Colorado River Water Availability Study

In 2007 the state legislature authorized $500,000 to study water availability in the Colorado River system considering current and future consumptive and non-consumptive needs with additional phases to be recommended by CWCB and the Basin Roundtables. Phase 1 of the study, which only looks at current water use, is currently in final draft form.[25] This study coordinated with the Front Range Vulnerability Study (see below) and used the same five future scenarios. Major findings from the study, which were broadly consistent with findings from the *Climate Change in Colorado* report, include a very large range of future water supplies due to uncertainties about runoff changes and large increases in future West Slope agricultural water demands. The study also found that future flows decreased from north to south across the state, in line with global climate model predictions. An additional study phase is pending.

Snowmelt and Runoff Timing Study

In 2007 the legislature authorized a snowmelt and runoff timing study to be conducted by the USGS with additional work on changes in temperature and precipitation at snow measuring stations.[26] This study was recently published in a peer-reviewed journal. It confirms that over a recent 30-year period, snowmelt timing has advanced by two to three weeks and winter temperatures have increased by nearly 5°F.

20. CDM, 2010: Municipal and Industrial Gap Analysis. September 17. [Available online at cwcbweblink.state.co.us/weblink/0/doc/145241/Electronic.aspx?searchid=31148d48-d968-4bee-a312-a6e66b1d7637.]
21. CWCB, 2010: Draft SWSI 2010 Municipal and Industrial Water Conservation Strategies. November.
22. See CWCB, *Reconnaissance Level Cost Estimates for Agricultural and New Supply Strategy Concepts*, 2010 for a discussion of these projects. [Available online at cwcbweblink.state.co.us/weblink/0/doc/143892/Electronic.aspx?searchid=bbbbf69b-ff6e-4950-9110-1846bbbaa99e.]
23. cwcb.state.co.us/water-management/drought/Pages/StateDroughtPlanning.aspx
24. [Available online at cwcb.state.co.us/water-management/flood/Documents/FloodMitPlanFinalDraft2010.pdf.]
25. See CWCB CRWAS web page. [Available online at cwcb.state.co.us/technical-resources/colorado-river-water-availability-study/Pages/main.aspx.]
26. Clow, D., 2010: Changes in the Timing of Snowmelt and Streamflow in Colorado: A Response to Recent Warming. Journal of Climate, 23, 2293-2230.

Weather Modification

The CWCB administers the state weather modification program, which has invested in cloud seeding research across the state and hail suppression activities in the San Luis Valley and Weld County.[27] For the last several years the states of Wyoming and Utah have pursued large-scale weather modification efforts in the Colorado River Basin as well.[28] The efficacy of weather modification programs is subject to debate.[29]

CWCB Climate Change Technical Advisory Group

The Climate Change Technical Advisory Group was created to help promote collaboration and critical partnerships between the federal entities, state agencies, and local governments and water providers. This technical task force has been charged with evaluating and vetting technical data and water adaptation strategies being contemplated to meet future water supply needs in the face of potential climate change impacts. They have played a critical role in reviewing both the methodology and results of the Colorado River Water Availability Study and the State Drought Plan as they pertain to climate change's potential impacts on water resources.

Climate Risk Conferences and Workshops

The Governor's Conference on Managing Drought and Climate Risk was held in October 2008 in Denver. It was attended by over 200 individuals from across the state. State government attendees included representatives from DNR, DWR, CWCB, CDPHE, and DOW; federal attendees included Environmental Protection Agency (EPA) and Bureau of Reclamation employees; numerous NGOs and water providers attended as well. Susan Solomon, a NOAA scientist based at the Earth System Research Laboratory in Boulder and the co-chair of Working Group I of the IPCC Fourth Assessment, presented the keynote address. The CWCB also held three workshops entitled "Dealing with Drought" in Castle Rock, Glenwood Springs and Durango in 2009.[30] In addition to CWCB personnel, these all- day workshops featured University of Colorado Western Water Assessment scientists, the state climatologist from Colorado State University, and federal representatives from the National Integrated Drought Information System (NIDIS).

Colorado River Compact Compliance Study

Under the provisions of the 1922 Colorado River Compact, Colorado (with all other Upper Basin states) is potentially subject to curtailment of a portion of its Colorado River water rights.[31] In some years up to 50 percent of the municipal supply on the Front Range may be subject to curtailment. Curtailment has long been thought unlikely under current demands. However, the current Colorado River drought—which began in 2000 and has caused Lakes Mead and Powell to drop from full to half full in 2010—has refocused attention on this possibility. Recent scientific studies and work by Reclamation suggest that supply has exceeded demand in recent years and various recent studies have indicated that the Colorado River may lose between 6 and 20 percent of its flow by 2050 due to warming.

In 2008 the state legislature authorized $500,000 for a Colorado River compact compliance study to investigate how the state would handle water rights curtailments.[32] The additional funding was requested in part because of new urgency surrounding low Lake Mead water levels and the possibility that the Lower Basin states may be subject to the first-ever declared shortage as early as 2012.[33] The CWCB has completed contracting and the study will begin shortly. It will identify water rights in Colorado that are

27. cwcb.state.co.us/water-management/water-projects-programs/Pages/%C2%ADWeatherModificationProgram.aspx and www.ral.ucar.edu/projects/wyoming/
28. www.ral.ucar.edu/projects/wyoming/
29. National Research Council, 2003: Critical Issues in Weather Modification Research [available online at www.nap.edu/openbook.php?record_id=10829&page=3#]; Orville, H.D., B.A. Boe, G.W. Bomar, W.R. Cotton, B.L. Marler, and J.A. Warburton, 2004: A Response by The Weather Modification Association to the National Research Council's report titled "Critical issues in weather modification research". Weather Modification Association, Fresno, CA. [Available online at www.weathermodification.org/images/FinalReport.pdf.]
30. wwa.colorado.edu/climate_change/drought09.html
31. *Present Perfected Water Rights* are unimpaired by the Colorado River Compact; all other water rights are subject to curtailment. *Present Perfected Water Rights* has multiple definitions but in some cases is defined to be rights existing at the time the Compact was signed on November 24, 1922.
32. See HB08-1346 and cwcb.state.co.us/public-information/board-meetings-agendas/documents/jul2010/30.pdf.
33. Lake Mead is currently at a level seen only once before, during its initial filling in May 1937. It is seven feet above the level at which a shortage will be declared.

not subject to curtailment; investigate methods to avoid, delay, or minimize curtailments; and consider ways to implement curtailments.

Water-Energy Study

Recent federal, state and NGO reports have identified the connection between water and energy as critical.[34] In short, most electrical power generation uses some form of water cooling (see chapter 5, Electricity Sector), and, conversely, water providers use energy to treat and pump water. With respect to the latter issue, the topography of the state of Colorado has historically allowed most water providers to move water via gravity without the need for significant pumping. However, because most of the easily available water has been developed, many new water development projects frequently have to work against gravity.[35] The embedded energy of these new water projects can be quite large because Colorado's topography is significant and water is heavy.[36] Pumping water is effectively hydropower in reverse. If such projects are powered by fossil fuels, they may emit significant greenhouse gases and may be subject to higher costs should a price be put on carbon emissions in the future. (See discussion of proposed new NEPA EIS standards for greenhouse gas emissions, below under NEPA Compliance.)

In 2009 the CWCB commissioned a study, "Water Conservation = Energy Conservation", on the energy use by water providers and consumers.[37] Key findings from the report indicate that the energy intensity of current supplies varies by a factor of five with older supplies (e.g., Denver) being much more efficient than newer supplies (e.g., Parker Groundwater and Southern Delivery System). Further, conserving water can save large amounts of energy by reducing pumping where it occurs and by reducing water heating everywhere, an intensive use of energy due to the very high "specific heat" capacity of water.

Interbasin Compact Committee and Basin Roundtables

In 2005 the state legislature passed the Water for the 21st Century Act,[38] which authorized the Interbasin Compact Committee (IBCC). It also created Basin Roundtables. The IBCC is a 27-member committee designed to facilitate discussions among basins, and it includes stakeholders beyond the water management sector.[39] The Basin Roundtables were established for each of the eight major basins in Colorado[40] and metropolitan Denver to outline basin-specific assessments of future water supply and demand and to propose projects and methods to help meet future consumptive and non-consumptive demands.[41] Specifically, the Basin Roundtables are tasked with identifying consumptive water needs, non-consumptive water needs, available water supplies, and proposed projects to meet needs. The extent to which climate change is explicitly included in the process is determined by each roundtable, but the integrated process defined by the SWSI provides an opportunity for integration of climate change in water resource planning. The IBCC 2009 Annual Report mentions that climate change is an issue that deserves further study and discusses how climate change will be incorporated into the Colorado River Water Availability Study (CRWAS) and the drought plan (see above). The 2010 IBCC Annual Report briefly mentions climate change in the context of CRWAS. In late 2010 the IBCC issued a report to the new governor outlining its accomplishments over the past four years and detailing a 2011 work plan. The report does not mention climate change explicitly, although among many findings it does discuss the need to minimize the risk of compact curtailments due to uncertain future water availability.[42]

34. DOE, 2006: Energy Demands on Water Resources: Report to Congress on the Interdependency on Energy and Water [available online at www.sandia.gov/energy-water/docs/121-RptToCongress-EWwEIAcomments-FINAL.pdf]; Texas Water Development Board, 2008: Water Demand Projections for Power Generation in Texas. [Available online at http://www.twdb.state.tx.us/RWPG/rpgm_rpts/0704830756ThermoelectricWaterProjection.pdf.]
35. See CWCB, *Reconnaissance Level Cost Estimates for Agricultural and New Supply Strategy Concepts*, 2010 for a discussion of these projects. [Available online at cwcbweblink.state.co.us/weblink/0/doc/143892/Electronic.aspx?searchid=bbbbf69b-ff6e-4950-9110-1846bbbaa99e.]
36. In some cases, these projects may recuperate some, but not all, of the embedded pumping energy as the water descends.
37. [Available online at cwcbweblink.state.co.us/WebLink/0/doc/138742/Electronic.aspx.]
38. See HB 05-1177. [Available online at www.state.co.us/gov_dir/leg_dir/olls/sl2005a/sl_314.pdf.]
39. cwcb.state.co.us/about-us/about-the-ibcc-brts/Pages/main.aspx/Templates/Home.aspx
40. Arkansas Basin, Colorado Basin, Gunnison Basin, North and South Platte Basins, Rio Grande Basin, Southwest Basin, and Yampa/White Basin.
41. cwcb.state.co.us/water-management/basin-roundtables/Pages/main.aspx
42. IBCC report, December 15, 2010. [Available online at cwcbweblink.state.co.us/WebLink/ElectronicFile.aspx?docid=146566&searchid=e0e845ca-f8c6-4efd-8e75-df2d9bf3a9d9&&dbid=0.]

Joint Front Range Climate Change Vulnerability Study (JFRCCVS)

Colorado water utilities, in partnership with the CWCB, have begun to investigate how to incorporate climate change into planning. They joined together in 2008 to invest collectively in climate and hydrology modeling efforts.

Municipal water providers in Colorado have typically run their system yield models using historical data sequences, including water that was legally divertible by the utility during the historical period. In the future, with changes in runoff timing, water rights are likely to yield different amounts of water. The city of Boulder, for example, believes that its storage rights may in fact yield more water because fewer plains farmers will be able to divert as they have historically when runoff timing shifts earlier in the spring. Under climate change this modeling practice, developed to avoid the complications of modeling water rights in an entire basin, will no longer be suitable to determine legally divertible flows.

In order to properly model such future runoff and water rights behavior, Denver Water; the Northern Colorado Water Conservancy District; the cities of Aurora, Boulder, Fort Collins, and Colorado Springs; and the CWCB led a major initiative to design "a unified regional approach to assess changes in the timing and volume of hydrologic runoff that might be expected from several climate change scenarios"[43] by 2040 and 2070. Hydrology models that produce runoff from precipitation and temperature were linked with water rights models to produce streamflows and divertible flows. The National Center for Atmospheric Research (NCAR) and Riverside Technology, with limited support from the Western Water Assessment, performed the work, funded primarily by the Water Research Foundation.[44] Although the extent to which each participant will use the scenarios in planning remains to be determined, this effort represents a move toward including climate in the suite of available data sets that water utilities might use for planning.

Federal Colorado River Basin Study

Concurrently but independently of CRWAS, Reclamation is carrying out a $2 million two-year study of water supply and demand in the Colorado River Basin that should be completed in January 2012.[45] The "Basin Study" is co-sponsored and co-funded by the Basin states, including Colorado, and aims to "define current and future imbalances in water supply and demand in the Colorado River Basin and the adjacent areas of the Basin states that receive Colorado River water for approximately the next 50 years, and to develop and analyze adaptation and mitigation strategies to resolve those imbalances."[46] The CWCB has an individual designated to work with Reclamation's team of federal employees and consultants working on the study.

Water Utility Climate Alliance and Denver Water

Denver Water was one of the founding members of the Water Utility Climate Alliance (WUCA), a group of now 11 large utilities in the United States dedicated to (1) improving and expanding climate change research, (2) promoting and collaborating in the development of adaptation strategies, and (3) identifying and minimizing greenhouse gas emissions.[47] WUCA was founded in 2007. It is pursuing a variety of activities and recently released two white papers, one on climate modeling[48] and one on decision making under uncertainty.[49] The latter paper was managed and partially authored by Denver Water. The states of Colorado and California have participated in this initiative at various times.

Denver Water was one of the first utilities to hire a full-time staff member devoted to incorporating climate into planning. Denver Water indicated that large utilities have significant resources that can be devoted to climate preparedness, unlike smaller utilities. The utility suggests that the uncertainties in all future climate studies should be fully disclosed so that such efforts are not misused. They also indicated that monitoring the current climate and making future projections is relatively easy to do, but planning for a wide range of future outcomes is very difficult.

43. www.waterresearchfoundation.org/research/TopicsAndProjects/projectSnapshot.aspx?pn=4205
44. Western Water Assessment, National Center for Atmospheric Research, Colorado Water Conservation Board
45. www.usbr.gov/lc/region/programs/crbstudy.html
46. www.usbr.gov/lc/region/programs/crbstudy/pos.pdf
47. www.wucaonline.org/html/
48. [Available online at www.wucaonline.org/assets/pdf/actions_whitepaper_120909.pdf.]
49. [Available online at www.wucaonline.org/assets/pdf/actions_whitepaper_012110.pdf.]

Colorado Department of Public Health and Environment Activities

The CDPHE operates as the implementation arm of the EPA for the Federal Clean Water Act and other legislation focused on water quality issues. The agency is engaged in projects led by the EPA that focus on climate change, such as the Climate Change Council. The CDPHE coordinates with DWR and CWCB through regular quarterly meetings and as needed. With respect to water quality planning, CDPHE acknowledges that some climate change-related decisions with respect to future water quality will need to be made in the relatively near future. Currently, the federal agencies and their rulings determine the degree to which climate change is included in water quality planning.

Barriers and Information Gaps Impeding Adaptation

The interviews and literature revealed numerous barriers and information gaps impeding implementation of climate adaptation in the water sector. They fall within several categories: (1) gaps in climate and hydrology monitoring; (2) gaps in hydrology and climate- related research on changes in extreme events, demands, runoff, and groundwater-surface water interactions; (3) gaps surrounding new sources of supply; (4) gaps relating to the need for new forms of planning that can encompass new forms of uncertainty, multiple futures, and the use of greatly expanded new information from models and monitoring stations; (5) gaps and barriers related to the need for better public communication and organizational structures to facilitate cross-agency communication; and (6) knowledge gaps about a number of legal issues relating to changes in timing of water rights, compact issues, water rights administration, the impact of federal environmental laws on state water rights, compliance with NEPA requirements, and federal constraints on the use of model output for planning and operations. These gaps are discussed below and options are supplied for resolution of the issue, if appropriate.

Climate and Hydrology Monitoring Gaps

The expansion and continuation of climate and streamflow monitoring was identified as critical. The need to support Colorado Agricultural Meteorological Network (COAgMet) stations, and high elevation observations, especially SNOTEL, was mentioned. At the heart of all science is quality data. Likewise, good management requires timely and accurate data.

Option: The state should continue to fund existing monitoring stations and add stations in areas identified as critical. In addition, it should work with the state climatologist, Natural Resources Conservation Service (NRCS), USGS, DWR-SEO, and others to identify data needs. Finally, the state needs to impress upon Congress the need for adequate funding for existing monitoring networks.

Climate and Hydrology Research Gaps

Changes in Existing Water Demands

Most future changes to water demand will likely occur as the result of three factors: increasing population, longer growing seasons, and higher temperatures. The Colorado River Water Availability Study investigated increases in agricultural demands in future climates due to the latter two factors. The 2010 SWSI updates on municipal and industrial demands included population growth but specifically did not include climate change. The 2010 SWSI update on water conservation strategies specifically did not include climate change, although it acknowledged the need for such analysis in the future. The 2010 SWSI update on agricultural demands only qualitatively discussed how agricultural demands might change. (See above discussion of SWSI for more information.) The Water Research Foundation has a new multi-year study on how demands will change under a new climate.[50]

In addition to changes in existing types of demands, a new type of demand in Colorado has recently been identified. The potential large-scale development of oil shale may create a significant water demand

50. Analysis of Changes in Water Use Under Regional Climate Change Scenarios, Water Research Foundation Project #4263. [Available online at www.waterresearchfoundation.org/research/topicsandprojects/projectSnapshot.aspx?pn=4263, accessed January 7, 2011.]

with unknown consequences for the state.[51]

Option: Additional research on how demands will change in the future is needed. The state can both commission studies as well as acquire such knowledge from other sources such as the Water Research Foundation.

Extreme Events

Climate modelers have recommended the use of multi-model mean output for use in regional climate change studies due to uncertainties about which climate model to use. This technique is frequently used with weather models and typically improves the accuracy of the projections. Unfortunately, in the case of water management, the use of the multi-model mean change in runoff obscures the extreme values. In many cases adapting to slowly changing means is easier than adapting to new extremes. Climate studies indicate that extreme events are already changing, will continue to exceed 20th century norms, and will get worse as the 21st century unfolds. Extreme values are critical for water management, both with respect to floods and droughts. Maximum 24-hour daily precipitation values, for example, are important in calculating the size of floods. The frequency, duration, and magnitude of heat waves and droughts are important for calculating water demands. Only recently has the scientific community begun to investigate the suitability of climate model output for such studies.

Recent research proposes that the impact of dust deposition on snow is changing both runoff timing and runoff amounts in the Colorado River Basin.[52] A recent peer-reviewed study suggests that runoff has advanced on average by three weeks and total flow volume has averaged 5 percent less since European settlement of the American West in approximately 1850. A network has been established in Colorado to monitor dust deposition and to inform water managers of likely changes in runoff timing.[53] It is uncertain how these events will change in the future, but projections for a drying American Southwest may increase dust deposition.

Option: Planning for changes in the means of events is not enough. The state should encourage planners to consider new types of extreme events in water planning for floods and droughts. Scenarios have been used by the IBCC for water demands, and by the CRWAS and the JFRCCVS for future climate. The CRWAS/JFRCCVS scenarios, originally designed to bracket future conditions of warm/hot and dry/wet, were found to be skewed to drier future conditions, making some desired analyses impractical. The state should work with the research community to understand how extremes are changing.

Hydrology Modeling Including Groundwater – Surface Water Interactions

The CRWAS and the JFRCCVS constructed "process" level hydrology models to convert snow and rain into runoff. Such models previously have not been used in Colorado for water management. These models are critical for future analyses because historical streamgage flows will no longer be usable in water yield modeling due to shifts in runoff timing and amounts. It is unclear how well the models in the JFRCCVS and the CRWAS performed and additional research is needed. There is also a great need to connect surface and groundwater models throughout the state.

Option: The state should continue to fund process level hydrology studies, move to include groundwater-surface water models, and work with researchers to investigate the performance of these models.

Gaps in Communication

Public Communication Problems

Climate change analysis uses information from an emerging science that is unfamiliar to many water resource managers. Accurately conveying climate change science to water managers and the public is a

51. GAO, Energy-Water Nexus, 2010: A Better and Coordinated Understanding of Water Resources Could Help Mitigate the Impacts of Potential Oil Shale Development [available online at www.gao.gov/new.items/d1135.pdf]; URS, 2008: Energy Development Water Needs Assessment. [Available online at cwcbweblink.state.co.us/weblink/ElectronicFile.aspx?docid=127791.]
52. Painter, T. H., J. S. Deems, J. Belnap, A. F. Hamlet, C. C. Landry, and B. Udall, 2010: Response of Colorado River runoff to dust radiative forcing in snow. Proceedings of the National Academy of Sciences.
53. www.snowstudies.org/codos1.html

major challenge. This includes making a distinction between what scientists are very certain is occurring at a global level and the regional uncertainties relating to the attribution of changes that are occurring and projections of future events. Recent surveys have documented a decline in public support for the idea of human-caused climate change since 2007. Lack of public support might prevent adoption of planning strategies related to climate adaptation.

Option: Emphasis on education and communication will be necessary to overcome this lack of knowledge. Examination of modes for effective messaging is an issue the state may need to consider. The Colorado Foundation for Water Education is funded by the CWCB and could be a valuable state partner for additional communication efforts. In addition to an overall message of the robust scientific support for human-caused climate change, the strong link between water and climate change needs to be relayed to the public and decision makers.

Inter-Organizational Communication and Coordination

Numerous climate change-related efforts are underway at the local, state, regional and federal level. Coordination across state agencies and among federal, state, regional, and local entities presents a challenge. The water agencies in the state are aware that changes in water resources extend beyond water management enterprises, and other partners need to be engaged for effective planning. Communicating and coordinating across multiple agencies can be a barrier to effective decision-making and solutions. The lack of flexibility within state agencies to cross agency boundaries was identified as a hurdle to planning and solutions. The Front Range is also home to numerous federal climate change efforts. Reclamation's research and development group is in Denver, the National Park Service's climate change effort is in Fort Collins, and two new Department of Interior Climate Science Centers are to be hosted by the University of Colorado and Colorado State University.

Option: The state should establish interagency groups to work on climate change adaptation. Also, the state should establish links with the many federal climate change efforts centered in Colorado.

Planning Gaps and Barriers

This section contains three related but distinct topics: planning for multiple futures, planning with new forms of uncertainty, and planning with vast amounts of new information. Although all bear some similarity, each has slightly different features and resulting needs and gaps.

Planning for Multiple Futures

Water management has traditionally relied heavily on historic datasets to plan for a single future. This is true of almost all aspects of water planning including reservoir sizing, future water demands, etc. Although a paradigm shift away from using the past as the sole guide to future planning is slowly occurring among the larger water providers, the same evolution in thinking about climate change by smaller players and the public has not yet happened. The JFRCCVS, CRWAS, SWSI, IBCC, and Colorado River Basin Study have all begun to use multiple futures for planning. This approach complicates analysis and solutions, but planning for a single future is no longer appropriate in most circumstances.

Identifying climate impacts and vulnerabilities is critical for such planning exercises. In many cases such identification can best be done using bottom-up techniques rather than trying to utilize uncertain model projections in a top-down fashion. Using normal climate variability as an input into such efforts, such as a repeat of the 1950s or 2002 droughts, can provide substantial lessons about water stress even in the absence of climate change.

Option: The state should encourage planning for multiple futures. The state should also sponsor a broad-based impacts and vulnerability study to support such activities. Identifying "no regrets" or "least regrets" solutions should assist with planning.

Planning Under Uncertainty

There are a number of significant uncertainties associated with planning for climate change. Future greenhouse gas emissions and climate model performance with respect to both temperatures and precipitation are two key uncertainties. How models handle natural variability has also arisen recently as a major concern. Distinguishing between shifts in means due to natural variability versus shifts due to climate change is critical. Similarly, understanding how year-to-year variability will change is also very important.

The science is also changing. The IPCC Fifth Assessment model runs will be completed in the next two years. These models have the potential to generate very different results from the IPCC Fourth Assessment which were the basis for the *Climate Change in Colorado* report and CRWAS results, among others. It may make sense to revise important analyses after every new generation of climate models, a period of roughly five years.

Conversely, much science is settled, even if imperfect. The same science-based statements about fundamental changes in the water cycle (e.g., more floods and more droughts) have been made for many years, even if exact quantification remains elusive. Qualitative statements backed up by sound science can be useful.

Future analyses should provide clarity to all parties about the key baseline assumptions. There is a desire among water resource planners for standardization of assumptions in these efforts so that comparisons can be made. Peer review of products would assist with understanding the usefulness of results.

Option: Water managers acknowledged that climate change was a critical driver for water supply planning less than five years ago. In the next five years it is unlikely that many of these key uncertainties will be reduced. In some cases, such as climate models, future projections may generate even broader ranges of results as the models become more complex. However, water managers in many cases now have a common climate-centric language to describe uncertainties and it should be possible to at least describe uncertainties and critical assumptions clearly. It is also important that regular updates of impacts and vulnerabilities be undertaken as the science evolves.

Planning with Numerous Sources of New Information

Scenario analysis with multiple futures, multi-model climate model output, and new monitoring data has the potential to cause "analysis paralysis." When knowledge is uncertain, it is human nature to collect more data, hoping that a path forward becomes clear. At some point, however, decisions have to be made.

Option: Efforts to step back and synthesize results from multiple sources can help overcome the daunting task of integrating vast amounts of new information. It is tempting to launch the next study without fully digesting the results and lessons from past efforts. Every few years the state should expend some effort to analyze results across studies to see if larger patterns can be discerned.

Gaps in Information about Water Sources to Meet New Demands

The SWSI process has identified three sources of water to meet future increases in demand: water conservation and efficiency, agricultural conversions, and development of new Colorado River supplies.[54] Each source has a mixture of trade-offs involving costs, environmental outcomes, reliability, economic dislocations, social acceptance, and other factors. Different players tend to put different values on each of these tradeoffs, further complicating analysis. The trade-offs among the sources are also likely to change in the future; for example a large carbon price might tend to favor conservation and efficiency, cheaper renewable power might favor projects with pumping, and changes in Colorado River flows in either direction would change the calculus of using this new source of supply.

Option: The SWSI should continue to support information-generating projects to assist with identifying trade-offs among the various potential solutions. Climate has the potential to make these

54. The IBCC technically identifies a fourth source, Identified Processes and Projects (IPPs) but this 'source' is usually just a proposed project using one or a combination of the first three sources.

trade-offs dynamic over time. Identifying solutions that are robust over time and robust to a changing climate will likely be very difficult. In some analyses it will be possible to analyze the future quantitatively while in other cases qualitative approaches may be more appropriate.

Legal and Administrative Knowledge Gaps

Changes in Timing of Existing Water Rights

Earlier runoff and lower flows later in the year are potentially problematic to all types of water rights. Some water rights are constrained by decree to only divert during some pre-defined time periods. In some cases changes in flow timing will affect junior rights, and in other cases senior rights. For example, as previously described, Boulder's junior water storage rights have frequently been called out by senior downstream agricultural rights during the spring runoff preventing their full use. One Boulder study suggests, however, that in the future their storage rights will be able to store water that previously would have been released to meet downstream demands. On the other hand, lower late-season flows have the potential to harm relatively senior water rights accustomed to diverting throughout the irrigation season. Understanding how water right yields will change as the hydrograph changes is critical to understanding Colorado's water future.

The potential impact of timing changes to instream flow rights is a special case of note. Instream flow water rights are quantified as the minimum flow necessary to preserve the environment; shifts in the timing of peak flows and diminished late season flows may decrease the effectiveness of these rights because the timing of environmental needs may change as flows decrease and water temperatures increase. Similarly, recreational in- channel diversions (RICDs), which provide in-channel water rights associated with recreational activities, have been decreed to protect historic flow conditions. With different runoff patterns RICD decrees may be ineffective for their purposes.

Option: One recent small study investigated these impacts but additional work by the state is warranted.[55]

Impact of Federal Environmental Laws on State Water Rights

Interviewees expressed concern that reductions in flow and changes in streamflow timing would interact with existing federal environmental laws including the Endangered Species Act, the Clean Water Act, and the Wild and Scenic Rivers Act, resulting in complications for the state and diverters. The rigidity of these environmental regulations was identified as a significant hurdle, and in some cases, it is unclear whether regulations designed to maintain aquatic ecosystems will be as successful under a new changed climate. Even if additional flexibility is introduced to these laws, transferring water rights between sectors to meet changing demands requires complex administration and costs. The state may be challenged to provide resources to support this influx of requests.

Option: The state needs to continue to monitor the interplay between federal laws and state water rights as climate change unfolds and as new or modified legislation is proposed.

National Environmental Policy Act Compliance for New Water Projects

New water projects generally require a federal Environmental Impact Statement (EIS) under NEPA. These impact statements have generally included significant historical streamflow modeling to quantify the impact of the project on the environment. On February 18, 2010, the Council on Environmental Quality (CEQ) issued draft NEPA Guidance on the Consideration of the Effects of Climate Change and Greenhouse Gas Emissions.[56] This document proposes that any projects subject to NEPA will need to analyze both the amount of greenhouse gasses they emit, as well as how the project will affect the environment as modified by climate change.

55. [Available online at wwa.colorado.edu/western_water_law/docs/WRCC_Complete_Draft_090308.pdf.]
56. See CEQ web page. [Available online at www.whitehouse.gov/administration/eop/ceq/initiatives/nepa] and document at ceq.hss.doe.gov/nepa/regs/Consideration_of_Effects_of_GHG_Draft_NEPA_Guidance_FINAL_02182010.pdf.]

The draft proposes that projects emitting more than 25,000 metric tons of CO2 per year, an amount that a large water pump-back project could exceed, be subject to significant analysis. The document also suggests that the "reasonably foreseeable conditions" used in the no-action alternative may need to include the probable impacts of climate change on baseline environmental conditions. The document uses examples of declining snowpack, increasing stream temperatures, and changes in water availability as issues of potential concern. The document recommends using peer-reviewed literature as the basis for such studies, including the U.S. Global Climate Change impacts report referenced in this document. Although it is unclear what the final recommendations may include, it seems likely that going forward any EIS not containing climate change in the environmental analysis may be subject to legal challenge.

Option: While the state is rarely the applicant for a water project requiring an EIS, providing input to the CEQ on the promulgation of these new rules should they be finalized will be critical. Future state work may be cited in EISs and the state should examine how any new rules may influence future SWSI updates.

Compact Planning and Water Rights Administration

Changes in runoff timing and amounts have the potential to complicate Colorado's interstate compact obligations as well as in-state water rights administration. The state engineer, CWCB, DNR, state attorney general's office and others have had many discussions about how to include climate change considerations in compact planning and water rights administration, especially in the context of the Colorado River. It is noteworthy that there is currently no model capable of investigating the failure of the Upper Basin states to deliver water under section III D (the 75 MAF/10-year clause) of the Colorado River Compact. The recent CRWAS study was only able to approximate these impacts using a simple model of the Upper Basin. Reclamation's Colorado River Basin study is also grappling with these issues.

Option: Colorado needs to continue to support analysis, research, and modeling surrounding these critical activities. Colorado may wish to investigate how to create an Upper Basin-wide model that can handle compact analysis. These are very sensitive issues and Colorado needs to perform this work without compromising its legal position or providing information deleterious to its cause to other states.

Federal Constraints on Using Model Output for Drought and Flood Planning

Another significant impediment to climate adaptation planning that was identified by the interviewees was the lack of authority to include model projections in planning. The state Water Quality Control Act does not allow CDPHE to use climate models to establish low flow requirements. Similarly U.S. Army Corps of Engineers regulations also impede the CWCB Flood Section from including projected floods in planning. This is in contrast to other federal planning requirements that are increasingly mandating the inclusion of climate change information.

Options: The state should monitor how national legislation such as the Clean Water Act and U.S. Army Corps of Engineer regulations might be modified to include use of model projections for drought and flood planning.

Overarching Recommendations

- CWCB efforts are critical for all water-related climate adaptation. These efforts are funded out of the CWCB Construction Fund through the annual Projects Bill. The governor should recognize the connection between the CWCB Construction Fund, the annual Projects Bill and climate adaptation activities.

- Adaptation coordination within DNR will require enormous effort given the size and breadth of the department. The governor should set the right tone, as well as commit significant resources if this effort is to succeed.

- The SWSI process needs to continue, and should explicitly consider climate variability and change. Quantitative studies should be performed whenever possible. Qualitative studies can be useful in all other cases.

4 Wildlife, Ecosystems, and Forests Sector in Colorado

Key Points

- Climate adaptation in this sector is strongly influenced by the activities of the federal resource management agencies, which manage 35 percent of Colorado's land base and share responsibility for managing Colorado's wildlife. Among state agencies, the Colorado Division of Wildlife (DOW) has the most prominent adaptation role in this sector.

- The most serious anticipated impacts of climate change include increasing frequency and severity of forest insect infestations and wildfires (both of which are believed to be occurring already), and changes in the hydrologic cycle that will impact fish and other aquatic organisms. These changes include a reduction in streamflow, a shift to earlier spring runoff, and an increase in stream and lake temperatures.

- Most state agencies in this sector are working to explicitly incorporate climate adaptation into their strategic planning and activities, most notably DOW. Several federal resource management agencies have recently released agency-wide strategic plans to adapt to climate change. The adaptation "toolkit" available to resource managers is largely that already used to manage ecosystems for other stressors, employed to increase the "resilience" of ecosystems and species to external change.

- Among the significant barriers to implementing adaptation planning in this sector are (1) the lack of ecological data and models to bridge from climate projections (which are themselves seen as too

uncertain) to specific climate impacts on ecosystems, and (2) lack of coordination among the state and federal agencies trying to implement climate adaptation.

- Overarching options for facilitating adaptation for this sector provided by interviewees were to (1) promote interagency coordination in adaptation planning and implementation and (2) continue to build state agency capacity to implement adaptation. Both would be usefully manifested in carrying out other key suggestions: (3) develop the ecological data to bridge from climate projections to climate impacts, (4) conduct a statewide vulnerability assessment for species and ecosystems, and (5) monitor the effects of adaptation strategies that are implemented.

Introduction

This chapter discusses climate adaptation efforts in the management of wildlife species and vegetation, and other wildlife habitat, across Colorado. It pays particular attention to the state's forest resources because of the sensitivity of other sectors, including outdoor recreation and water, to forest conditions. Although wildlife, ecosystems, and forests comprise an unwieldy "sector" due to the complex mosaic of land ownerships and uses, and resource agency responsibilities and stakeholder interests, we consider them all together here because wildlife and their habitats—including forests—are interdependent and are highly sensitive to climate and transcend land ownership boundaries.

Sources for This Chapter

The CCPP research team interviewed seven organizations for the Wildlife, Ecosystems, and Forests chapter: the state Department of Natural Resources, Colorado Division of Wildlife, Colorado State Forest Service, the White River National Forest (U.S. Forest Service), the U.S. Fish and Wildlife Service, The Nature Conservancy, and Trout Unlimited. In addition, CCPP interviews with Colorado State Parks and the Western Governors' Association, and an informal conversation with staff at the U.S. Forest Service Rocky Mountain Research Station in Fort Collins, informed the discussions in this chapter. We did not interview representatives from other organizations that are important to this sector, such as the National Park Service and the Bureau of Land Management.

We consulted two main assessments of the scientific literature on climate impacts—*Climate Change Impacts in the United States*, produced by the U.S. Global Change Research Program (USGCRP), and the Working Group II report of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC). Another product of the USGCRP, the SAP Report 4.4 on adaptation options for climate-sensitive ecosystems and resources, was also consulted regarding both climate impacts and adaptation. For the discussions of adaptation planning and implementation, we also reviewed planning documents from the interviewed agencies, as well as documents from other key resource management agencies. These documents are described in the text and tables that follow.

Overview of the Sector in Colorado

Colorado has extraordinarily diverse ecosystems, from riparian cottonwood woodlands in far eastern Colorado to alpine tundra atop high mountain peaks. This diversity is driven by variation in climate—which is largely a function of elevation—and also by topography, geology, proximity to water, and past and present land use. More than 3,000 plant species give structure to these ecosystems, providing habitat for about 750 species of mammals, birds, reptiles, amphibians, and fish.[1] Forest and woodland ecosystems cover just over one-third of the state. Currently, 18 wildlife and 13 plant species in Colorado are federally listed as threatened or endangered under the Endangered Species Act, and another 15 wildlife species are state-listed as threatened or endangered.[2]

Planning and management within the wildlife, ecosystems, and forests sector in Colorado is dominated by public natural resource agencies. This is due, first, to the land ownership pattern: fully 40 percent of

1. Landscope Colorado (NatureServe) website. [Available online at www.landscope.org/colorado/plants-animals/, accessed November 2, 2010.]
2. Colorado Division of Wildlife website. [Available online at wildlife.state.co.us/WildlifeSpecies/SpeciesOfConcern/ThreatenedEndangeredList/ListOfThreatenedAndEndangeredSpecies.htm, accessed November 2, 2010.]

the statewide land base is publicly owned and managed: 35 percent by the federal government,[3] and five percent by state government.[4] Public land ownership is particularly concentrated in the forested mountainous region of the state, and the western plateau region, reaching over 90 percent of the land base in some mountain counties. Conversely, very little of the eastern plains and the intermountain grassland parks are publicly owned. Second, the wildlife resources of the state, regardless of whose land ownership they occur on, are managed by the Colorado Division of Wildlife (DOW) in partnership with the U.S. Fish and Wildlife Service and other agencies.

Wildlife, ecosystems, and forests provide extraordinary economic and other benefits to the state of Colorado. Hunting, fishing, and wildlife viewing together were estimated to have a total economic impact of $2.4 billion in 2007[5] with the larger impact of all outdoor recreation activities estimated at $10–15 billion.[6] The forest products industry in Colorado generated about $100 million in sales of manufactured products in 2002.[7] More importantly, wildlife and ecosystems provide abundant non-economic benefits through the provision of "ecosystem services" such as regulation of local climate, water quantity, and water quality; soil formation, photosynthesis, and nutrient cycling; and provision of aesthetic, spiritual, and other cultural benefits, including "amenity value." [8,9]

State-Level Regulatory and Policymaking Agencies

The State Department of Natural Resources (DNR) provides policy and management oversight for the Division of Wildlife, State Land Board, and State Parks. It also represents the governor's interest in forest health by convening and chairing the Forest Health Advisory Council.[10]

Of the DNR agencies, the Division of Wildlife (DOW) has the most far-reaching influence on Colorado ecosystems and their management. DOW is the operating arm of the State Wildlife Commission, and manages the fish and wildlife that occur across all lands and waters of the state. DOW also manages more than 300 state wildlife areas, which comprise 550,000 acres, and also leases 550,000 acres of state trust lands (see below) for hunting, fishing, and other recreation. They work closely with the U.S. Fish and Wildlife Service in managing wildlife species (such as endangered fish) for which they share responsibility. DOW's activities are guided by a 10-year strategic plan (the current one covers 2010-2020) and a State Wildlife Action Plan (SWAP) mandated by federal legislation.[11] The statutory authority for DOW calls for "wildlife and their environment" to be "protected, preserved, enhanced, and managed for the use, benefit, and enjoyment of the people of this state."[12]

State Parks manages 42 parks covering 225,000 acres statewide. While their interview for this report was mainly focused on recreation concerns, commensurate with their management emphasis on recreation, they do manage diverse landscapes and ecosystems with complex challenges similar to those reported by the larger land management agencies.[13] The enabling legislation for State Parks states that "the natural, scenic, scientific, and outdoor recreation areas of this state are to be protected, preserved, enhanced, and managed for the use, benefit, and enjoyment of the people of this state[14] and visitors of

3. CRS, 2004: *Federal Land Management Agencies: Background on Land and Resources Management.* Congressional Research Service Report to Congress, updated August 2, 2004.
4. Colorado Department of Agriculture, 1997: "Total CO Land Ownership". Table prepared by T. Frank for the Colorado Department of Agriculture, Resource Analysis Section, January.
5. BBC Research and Consulting, 2008: The Economic Impacts of Hunting, Fishing and Wildlife Watching in Colorado. Report prepared for the Colorado Department of Wildlife, September 26, 22 pp.
6. Colorado State Parks, 2008: *Statewide Comprehensive Outdoor Recreation Plan* (SCORP).
7. Colorado State Forest Service (CSFS), 2010: Colorado Statewide Forest Resource Assessment. Colorado State Forest Service, Colorado State University, Fort Collins, CO, 79 pp.
8. Millennium Ecosystem Assessment, 2005: Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, 86 pp.
9. The economic value of these ecosystem services at the global scale has been estimated at $33 trillion per year (Costanza, R., R. D'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, R.G. Raskin, P. Sutton and M. van den Belt, 1997: The value of the world's ecosystem services and natural capital. Nature, 387, 253-260.) A very crude re-scaling of this figure to Colorado suggests a value of ~$20 billion per year for these ecosystem services.
10. DNR EDO interview.
11. DOW interview.
12. C.R.S. 33-1-101(1).
13. State Parks interview.
14. C.R.S. 33-10-101

this state." In addition, State Parks oversees the management of Colorado's 114 registered or designated natural areas, which preserve important natural resources found throughout the state.[15]

The State Land Board manages 2.8 million acres of state trust lands, which are mainly in a "checkerboard" pattern of two sections, one square mile each, per township (36 square miles) across the state.[16] They manage those lands with the objective of generating sustainable revenue for state trusts, with 90 percent going to K–12 schools, largely through agricultural, mineral, oil, and gas leases.[17]

The Colorado State Forest Service (CSFS) is an arm of Colorado State University that acts on behalf of the state under a memorandum of understanding with DNR. It is largely an outreach agency, serving private forest owners with staff in 17 districts across the state. It also manages the 72,000-acre Colorado State Forest in Jackson County, on behalf of the State Land Board. The State Forest has served as a demonstration area for forest treatments.[18]

Finally, the Colorado Water Conservation Board (CWCB), described in more detail in chapter 3, (Water Sector), has important roles in the management of aquatic and riparian ecosystems. The CWCB is responsible for the appropriation, acquisition, protection, and monitoring of instream flow water rights and natural lake level water rights, both of which are used to protect habitat for fish, waterfowl, and other aquatic species.[19] The CWCB must also review and approve DOW's wildlife mitigation plans for new water projects in the state. Finally, it administers funding for habitat protection and mitigation through the Colorado Watershed Restoration Fund, the Colorado Healthy Rivers Fund, and the Fish and Wildlife Resources Fund.

Federal Agencies

As stated earlier, the federal public land management agencies manage over one-third of the state, and exert particular influence on forested lands and forestry. The U.S Forest Service (USFS), under the Department of Agriculture, is the single largest land manager in Colorado, with 14.5 million acres in 11 national forests and two national grasslands.[20] The USFS mission is "to sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations." Individual forests are governed by forest plans, which are updated on a roughly 10-year cycle, consistent with the authority of the 1974 National Forest Management Act, NEPA and other federal environmental statutes.

Other key federal agencies are housed within the Department of the Interior (DOI). The U.S. Fish and Wildlife Service (USFWS) is responsible for protecting wildlife, fish, and plant species and their habitats under the Endangered Species Act, Migratory Bird Treaty Act, Bald and Golden Eagle Protection Act, and other federal environmental laws.[21] In addition to working with the state DOW to manage many different species in Colorado, they provide funding to DOW to support the development of the SWAP.[22] USFWS also manages eight national wildlife refuges in Colorado covering about 85,000 acres. The National Park Service (NPS) manages 12 national parks, national monuments, and other sites in Colorado totaling 650,000 acres. Under the 1916 Organic Act, the NPS mission is "[to] preserve unimpaired the natural and cultural resources and intrinsic values of the National Park System for the enjoyment, education, and inspiration of this and future generations." The Bureau of Land Management (BLM) manages 8.4 million acres across the state, predominantly in the grasslands, shrublands and pinyon-juniper woodlands of western Colorado. The 1976 Federal Lands Policy and Management Act provides BLM with authority to manage its lands for multiple uses, including resource extraction and recreation. By managing major

15. Colorado State Parks, 2010: Colorado State Parks 2010 Strategic Plan.
16. See the state ownership map maintained by the CSU NREL COMaP project [Available online at www.nrel.colostate.edu/projects/comap/]
17. DNR EDO interview.
18. CSFS interview. The utility of the State Forest as a demonstration area for forest treatments has been severely impaired by the Mountain Pine Beetle infestation, which has caused widespread tree mortality over the past several years.
19. CWCB Instream Flow Program web page. [Available online at cwcb.state.co.us/environment/instream-flow-program/Pages/main.aspx, accessed November 18, 2010.]
20. The acreages managed by the USFS and other federal agencies in Colorado provided in this section are taken from CRS, 2004, *Federal Land Management Agencies: Background on Land and Resources Management.*
21. USFWS, 2008: Agency Overview. U.S. Fish and Wildlife Service, November, 2 pp.
22. USFWS interview.

water projects, the Bureau of Reclamation exerts control on streamflow levels on most of the state's major rivers. Reclamation also works with USFWS and CWCB on endangered species recovery programs in the Colorado, Yampa/White, Gunnison, San Juan, and South Platte basins. Reclamation's activities are described in more detail in chapter 3 (Water).

In addition to field offices throughout the state associated with their specific landholdings, all of the aforementioned federal agencies have regional offices in the Denver area, and most also have national-level technical staffs co-located with those offices or elsewhere along the Front Range.

Non-Governmental Organizations (NGOs) and Other Entities

Many nongovernmental entities (NGOs), including hunting and fishing organizations and environmental NGOs, also exert considerable influence on management of wildlife and ecosystems in Colorado. Three of the more influential such entities are highlighted here. The Nature Conservancy (TNC) protects ecologically important lands and waters to preserve plants, animals, and ecosystems. TNC in Colorado has a close consultative relationship with state and federal natural resource agencies[23] and also manages 437,000 acres across the state, on 14 TNC-owned preserves and in cooperation with other landowners.[24] The Western Governors' Association (WGA) is a non-partisan organization serving the governors of 19 Western states and three U.S.-flagged islands. WGA helps the states integrate science into decision-making by facilitating information transfer between the states, and from federal agencies and other entities to the states. WGA has convened a Climate Change Adaptation Working Group that has engaged 13 of the 19 states, as well as a Western Wildlife Habitat Council.[25] Trout Unlimited works to conserve, protect, and restore coldwater fisheries and their watersheds. Their work in Colorado and five other western states is under the auspices of their Western Water Project, which emphasizes protection of instream flows to sustain fish habitat.[26]

Climate Change Impacts on Wildlife, Ecosystems, and Forests

Climate is a key determinant of the spatial distribution and characteristics of ecosystems and species. It also controls or modulates important ecosystem disturbances such as fire and windthrow.[27] In any given location, these ecosystems and species have generally adapted to the historical or natural climate variability that has occurred there. Each species has a particular climatic "envelope" and corresponding ability to adjust to change. As the future climate moves beyond the bounds of the natural climate variability to which these ecosystems and species have adapted, significant impacts are expected.

Ecosystems in Colorado are already impacted by many non-climatic stressors caused by human activity: habitat loss due to land use change, increasing water diversions, competition from introduced non-native species, changes in forest condition due to fire suppression, barriers to movement such as highways, and others.[28] The climate change impacts described below will generally tend to exacerbate the effects of these other stressors, and vice versa.

The list of climate change impacts on ecosystems that our interviewees collectively identified to be occurring now, or that they expect to occur in the future, covers most of the ecosystem impacts relevant to Colorado found in assessments of the scientific literature (table 4-1).[29, 30, 31, 32]

23. TNC interview.
24. TNC: *Colorado's Last Great Places: Nature Conservancy Preserves and Cooperative Projects You Can Visit*. The Nature Conservancy Colorado, no date.
25. WGA interview.
26. TU interview.
27. CCSP, 2008: *Preliminary review of adaptation options for climate-sensitive ecosystems and resources*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Julius, S.H., J.M. West, eds. U.S. Environmental Protection Agency, Washington, DC, USA, 873 pp.
28. DOW interview.
29. Karl, T. M., Mellilo, J. M., and T. C. Peterson, eds., 2009: *Global Climate Change Impacts in the United States*. Cambridge University Press, 188 pp.
30. CCSP, 2008: *Preliminary review of adaptation options for climate-sensitive ecosystems and resources*.
31. Wagner, F. H., ed., 2009: *Climate Warming in Western North America: Evidence and Environmental Effects*. University of Utah Press, 167 pp.
32. Fischlin, A., G.F. Midgley, J.T. Price, R. Leemans, B. Gopal, C. Turley, M.D.A. Rounsevell, O.P. Dube, J. Tarazona, A.A. Velichko, 2007: Ecosystems, their properties, goods, and services. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, eds., Cambridge University Press, Cambridge, 211-272.

Table 4-1

Ongoing and/or potential climate change impacts on Colorado's wildlife, ecosystems, and forests, according to scientific assessments. Impacts also mentioned in the interviews are in italics.
Increasing frequency and severity of forest insect infestations
Increasing frequency and severity of wildfires
Changes in the hydrologic cycle that impact fish and other aquatic organisms: • *Reduction in overall streamflow* • *Shift to earlier spring runoff* • *Warming of stream and lake temperatures*
Northward and upward shifts in plant and animal ranges, also causing ecosystems to "break up" as some organisms adjust faster than others
Shifts in the timing of annual life events for plants and animals
Increased range and spread of wildlife disease pathogens
Decrease in forest productivity and increase in tree mortality, due to increased drought stress
Increased risk of desertification in dryland ecosystems
Overall decrease in biodiversity because of the above impacts

The most frequently cited impact was the mountain pine beetle (MPB) infestation, which along with other insect infestations is causing widespread tree mortality in Colorado's forests. While interviewees noted that climate change is not the only cause or precondition of these infestations, they generally saw it as an important driver and one likely to cause increasing frequency and severity of insect infestations in the future,[33, 34] a view supported by the USGCRP report.[35]

Increasing frequency and severity of wildfire was also cited in several interviews. This impact is similar to insect infestations in that it was seen by interviewees to be already manifesting in Colorado, with many large and destructive wildfires in the state occurring since 2000. This view is consistent with studies that have detected a significant increase in the length of the fire season and the number of fires across the western United States since 1980, and project those trends to continue in the future, as warming leads to yet longer fire seasons and drier fuels.[36]

Several of the climate impacts cited in the interviews reflect changes in the hydrologic cycle that would negatively affect fish and other aquatic organisms.[37, 38, 39, 40] Interviewees anticipate reductions in overall streamflow as warmer temperatures increase evapotranspiration along with a shift in the seasonal timing of streamflows, with peak runoff occurring earlier as warming enhances the spring snowmelt. Interviewees also expect increases in stream and lake temperatures as air temperatures warm and flow decreases. Reduced flows and warmer water temperatures were seen as facilitating the spread of non-native aquatic species.

In both aquatic and terrestrial environments, interviewees expect northward and upward shifts in the ranges of animal and plant species and ecosystems, in response to warming temperatures.[41, 42] This general upward movement means that high-elevation species like cutthroat trout[43] are prone to contraction of their range, if not vulnerable to extinction. Similarly, interviewees anticipated that warming would shift the phenology (the timing of life-cycle events such as flowering and hibernation) of both plants and animals, independent of changes in range.[44]

33. DNR EDO interview.
34. CSFS interview.
35. 2009: *Global Climate Change Impacts in the United States*, p. 82.
36. 2009: *Global Climate Change Impacts in the United States*, p. 82.
37. USFS interview.
38. State Parks interview.
39. DOW interview.
40. TU interview.
41. USFS interview.
42. DOW interview.
43. TU interview.
44. DOW interview.

The question of relative vulnerability to climate change of the different ecosystem types and landscapes in Colorado, while not addressed in every interview, elicited varying responses. The TNC interviewee stated that the most climate-vulnerable ecosystems in Colorado were shortgrass prairie, fire-dependent forests, and aquatic ecosystems. He also noted that the most vulnerable species at present are plants.[45] The DOW representative enumerated the challenges facing each of the major ecosystems in the state but asserted that the information about climate vulnerabilities for these ecosystems was insufficient to allow a ranking of them according to vulnerability.[46]

Science syntheses of the impacts of climate change on wildlife and ecosystems in the western United States emphasize that all of the impacts cited in the interviews—not just increases in beetle infestations and fires—are already occurring, albeit at a slower pace now than is expected in the future, when warming will accelerate. These syntheses also identified additional likely impacts, relevant to Colorado, which were not enumerated in the interviews.[47, 48, 49] These impacts are shown without italics in table 4-1.

Potential Impacts from Climate Mitigation Efforts

The interviewee from TNC raised the issue of conflict between climate mitigation measures and the ability of ecosystems to adapt to climate change. He referred specifically to the threat that large-scale solar and wind power installations pose to habitat integrity and ecosystem resilience, due to their very large footprints on the land. He cautioned, "Don't ruin the thing you're trying to save from climate change."[50]

Current and Planned Adaptation Initiatives

Adaptive Capacity

The notion of "adaptive capacity" is more challenging to articulate in the context of this sector since it involves at least three dimensions: (1) the inherent ability of species and ecosystems to adapt to climate variability and climate change, recognizing that other human-caused stressors have already reduced this capacity in most cases; (2) the ability of ecosystem managers to use existing management strategies and tools[51] to promote that ecosystem/species adaptive capacity or *resilience* to climate and other stressors; and (3) the capacity of the ecosystem management systems themselves (e.g., planning frameworks, organizational structures, interagency coordination) to adjust in order to meet the challenges imposed by climate change. With respect to this third dimension, the TNC interviewee noted that, in TNC's basin-scale climate adaptation initiatives, "what you're really adapting are those management systems." Much of the discussion below is focused on this third dimension of adaptive capacity, specifically the development of new planning frameworks to guide adaptation.

Climate Adaptation Planning

Researchers in federal ecosystem management agencies, including the USFS and the NPS, first began discussing climate change impacts and the need for climate adaptation in the late 1980s and early 1990s.[52] At that time, the scientific literature describing the potential impacts of climate change on wildlife and ecosystems was just emerging but already had identified many of the impacts described in the previous section. Since then, that body of literature has expanded tremendously in scope and overall confidence, paralleling the expansion of the underlying climate science during that period.[53]

45. TNC interview.
46. DOW interview.
47. 2009: *Global Climate Change Impacts in the United States.*
48. Wagner, 2009: *Climate Warming in Western North America*.
49. Fischlin, et al, 2007: Ecosystems, their properties, goods, and services. *Climate Change 2007: Impacts, Adaptation and Vulnerability*.
50. TNC interview.
51. The DOW interviewee summarized these existing tools as "protecting, enhancing, and connecting important habitat". For more description of the adaptation "tool kit" for this sector, see CCSP, 2008, *Preliminary review of adaptation options for climate-sensitive ecosystems and resources.*
52. e.g., Tinus, R.W., 1995: Research Accomplishments of the Interior West Global Change Program: Management Implications. *Interior West global change workshop*, Tinus, R. W., Tech. ed, RM-GTR-262, USDA Forest Service Rocky Mountain Forest and Range Experiment Station, 1-4
53. Wagner, *Climate Warming in Western North America.*

The translation of this information into climate adaptation planning by agencies at the state and federal level has occurred slowly. The past several years, however, have seen an outburst of adaptation initiatives that collectively provide a useful framework for further adaptation planning and actions at the state level. It should be noted that many of these climate adaptation reports and plans were compelled by administrative action at a higher level (e.g., the U.S. Department of Interior) than the acting agency or agencies.

Table 4-2 summarizes the current status of climate adaptation planning, and future efforts that are contemplated, across four state and four federal resource management agencies. The text that follows describes the adaptation efforts at each agency and entity, as does table 4-3.

Table 4-2: Status of Climate Adaptation Planning and Contemplated Future Efforts at Selected State and Federal Resource Management Agencies, as of October 2010.

Agency	Agency-wide Climate Change Strategy/ Plan?	Climate change adaptation discussed in other agency-wide planning documents?	Intend to incorporate additional climate change data and information into planning?	Intend to conduct climate change vulnerability assessments for ecosystems?
DOW	No	Yes (*Strategic Plan for 2010-2020*)	Yes (*State Wildlife Action Plan*, by 2015)	**Yes**
CSFS	No	Yes (*Forest Strategy*)	Yes (*Forest Strategy,* periodic updates)	**Maybe**
State Parks	No	Yes (*Strategic Plan for 2010*) [54]	Yes	**Maybe**[55]
State Land Board	No	No	Possibly	**n/a**
USFS	Yes (7/2010)	n/a	Yes	**Yes (prototype ongoing)**
USFWS	Yes (9/2010)	n/a	Yes	**Yes**
NPS	Yes (9/2010)	n/a	Yes	**Yes**
BLM	**No**	**No**	**Yes**	**Yes (ongoing: *Rapid Ecoregional Assessments*)**

Colorado Forests – The CSFS and USFS

In 2010 the CSFS released the *Colorado Statewide Forest Resource Assessment*.[56] This and other statewide forest assessments were mandated by the forestry title of the 2008 Farm Bill. The USFS and the state foresters developed three national themes and accompanying strategic objectives to guide these assessments. While one of these strategic objectives is to "manage and restore trees and forests to mitigate and adapt to global climate change", this objective was not directly addressed in the *Forest Assessment*, although climate change is mentioned a number of times in the document in the context of ecological impacts. However, a companion planning document to the *Forest Assessment, the Colorado State Forest Strategy* (2010),[57] does list "Forest Resiliency and Adaptability due to changing Climatic Conditions" as one of ten threats to forests across the state and makes several recommendations specific to climate change (see table 4-3). The forest strategy is intended to be a dynamic document, to be updated as more information about specific climate change impacts becomes available.[58]

The state's role in climate adaptation for Colorado's forests is limited by the small forested land base actually controlled by the state, as well as the low percentage of private forest owners who participate in CSFS-led planning activities.[59, 60] Because the USFS manages roughly half of Colorado's forested lands, and

54. In the State Parks Strategic Plan for 2010, climate change is referenced as a facet of "Environmental Change", one of the "key issues and trends" considered in the plan. Climate change adaptation is discussed more explicitly in the 2008 SCORP. See the text and also chapter 7, Outdoor Recreation Sector, for more detail.
55. This depends on the availability of financial and technical support to carry out such assessments.
56. Colorado State Forest Service (CSFS), 2010: Colorado Statewide Forest Resource Assessment. Colorado State Forest Service, Colorado State University, Fort Collins, CO, 79 pp.
57. Colorado State Forest Service (CSFS), 2010: Colorado Statewide Forest Strategy. Colorado State Forest Service, Colorado State University, Fort Collins, CO, 24 pp.
58. CSFS interview.
59. DNR EDO interview.
60. CSFS, *Colorado Statewide Forest Resource Assessment.*

most of the high-elevation forests (above 9,000 feet),[61] they strongly influence the agenda for planning and management of the forest sector across the state.[62] In July 2010, the USFS released the *National Roadmap for Responding to Climate Change*,[63] which emphasizes the need to promote the resilience of forest ecosystems. Within Colorado, initiatives to build climate change planning and adaptation capacity are ongoing at several national forests.[64]

Wildlife—DOW, USFWS, and Others

DOW has just begun to incorporate climate change, in the broadest sense, into agency planning documents. The agency's 2010–2020 Strategic Plan discusses climate change in several places, most notably in a strategy under the objective of ensuring the long-term viability and maintaining diversity of native fish and wildlife (see table 4-3). Current DOW climate change adaptation efforts are aimed at refining their understanding and identification of crucial habitats and wildlife corridors, complying with the fish and wildlife provisions of the 2010 Colorado Drought Mitigation and Response Plan, and minimizing existing threats to terrestrial and aquatic wildlife systems. Examples of existing threats, in addition to climate change, include habitat type conversion, invasive species, urban/suburban development, and wildlife diseases/pathogens. In the near future, DOW intends to conduct climate adaptation planning more informed by specific quantitative analyses. They are embarking on a "climate change update" to the State Wildlife Action Plan (SWAP) to be completed by 2015, consistent with the September 2010 report[65] from the Climate Change Workgroup of the Western Association of Fish and Wildlife Agencies (WAFWA). This update to the SWAP is anticipated to include a vulnerability analysis of key habitats and priority species, filling in the knowledge gap alluded to in the previous section, as well as adaptation measures to increase resilience to climate change.[66] As a precursor to the SWAP climate change update, consensus will need to be developed on a suite of climate and ecological response models as well as future climate scenarios appropriate for Colorado's diverse topography and climate that can be used at an appropriate scale for predicting impacts to habitats and species.

USFWS

Like the USFS, the U.S. Fish and Wildlife Service has a long history of studying climate change and potential impacts to its managed resources. In September 2010, USFWS released its strategic plan for dealing with climate change (see table 4-3).[67] The plan follows the October 2009 order issued by Interior Secretary Salazar instituting a broad program of adaptation activities across that department's agencies, including the USFWS, National Park Service, Bureau of Land Management, and the Bureau of Reclamation.[68] A key component of that program is the establishment of regional Landscape Conservation Cooperatives (LCCs) to be led by USFWS with other DOI agencies, and the Climate Science Centers (CSCs), to be coordinated by the U.S. Geological Survey with universities and other federal agencies. The LCCs are management-science partnerships that "inform integrated resource management actions addressing climate change and other stressors within and across landscapes."[69] Three LCCs, which together cover the state of Colorado, have been established or are in that process: the Southern Rockies LCC (western Colorado), the Great Plains LCC (eastern Colorado), and the Great Northern LCC (far northwest Colorado)[70]. The DOW is engaged in collaborations with all three LCCs,[71] and the USFWS anticipates that the LCCs will provide the state with better tools to determine how best to meet management objectives under climate change.[72] Colorado

61. See table 2, CSFS, *Colorado Statewide Forest Resource Assessment*, p. 16.
62. DNR EDO interview.
63. USFS, 2010: *National Roadmap for Responding to Climate Change*. USDA Forest Service, July 2010, 30 pp.
64. e.g., the Climate Change Watershed Vulnerability Assessment Pilot Project. [Available online at www.fs.fed.us/rm/boise/AWAE/briefing/WVA_TechTran.pdf.]
65. WAFWA, 2010: *Multi-Sector Climate Change Adaptation Planning.* Report of the Climate Change Workgroup, Western Association of Fish & Wildlife Agencies (WAFWA), September 7, 28 pp.
66. DOW interview.
67. USFWS, 2010: *Rising to the Urgent Challenge: Strategic Plan for Responding to Accelerating Climate Change*. U.S. Fish and Wildlife Service, September, 32 pp.
68. US DOI, 2009: *Addressing the Impacts of Climate Change on America's Land, Water, and other Natural and Cultural Resources*. Order No. 3289, Washington, D.C.: U.S. Department of the Interior, Secretary of the Interior, September 14.
69. USFWS: *Landscape Conservation Cooperatives*. [Available online at www.fws.gov/science/shc/lcc.html, accessed October 30, 2010.]
70. The boundaries of all three LCCs extend well beyond Colorado's borders. See the LCC map at www.doi.gov/lcc/index.cfm.
71. DOW interview.
72. USFWS interview.

is covered by two CSCs: the Southwest CSC, operated by a consortium of six universities including the University of Colorado, and the North Central CSC, operated by a consortium led by Colorado State University, and also including the University of Colorado.[73]

State Parks

While State Parks has no plans to develop an agency-wide climate adaptation plan, the interviewed agency staff readily acknowledge that climate change will need to figure into their long-term planning and management.[74] The 2008 *Statewide Comprehensive Outdoor Recreation Plan (SCORP)*, for which State Parks was lead author, does discuss climate change, and makes several recommendations about inclusion of climate change information in statewide recreation planning. Climate change was also factored into the development of the goals and objectives in State Parks' Strategic Plan (2010)[75], although the language related to climate change is much less explicit than in the SCORP. The recently updated plan for Roxborough State Park also has some consideration of climate change, and may serve as a blueprint for future plans for individual parks. See chapter 7, Outdoor Recreation, for more discussion of State Parks with respect to climate adaptation.

State Land Board

The State Land Board has not explicitly addressed climate change in the planning for the state trust lands.[76] A recent strategic planning exercise included several action items through which climate change considerations may be introduced in the future into the way the board pursues its land management responsibilities.[77]

Other Federal Ecosystem Management Agencies[78]

The National Park Service (NPS), with a long history of climate change research similar to USFS and USFWS, has in the past several years moved to broadly incorporate climate adaptation into its activities through the NPS Climate Change Response Program (CCRP), now based in Fort Collins. The CCRP staff have established "scenario planning" as the framework for adaptation planning at the park level. According to NPS, scenario planning provides management relevance and a platform to develop and test decisions under a variety of plausible futures.[79] The nationwide *NPS Climate Change Response Strategy*, produced by the CCRP, was released in September 2010 (see table 4-3).[80]

The Bureau of Land Management (BLM) has until very recently taken only preliminary steps to address climate adaptation in its planning and management.[81] In 2010, the BLM began a program of Rapid Ecoregional Assessments (REAs), which will address climate change, along with other stressors, at the "ecoregion" level.[82] BLM will use the NatureServe Climate Change Vulnerability Index[83] as the basis for vulnerability assessments for species conservation targets.[84]

73. As with the LCCs, the regions covered by these CSCs extend beyond Colorado, although the boundaries are purposely vague. See the CSC map at www.doi.gov/whatwedo/climate/strategy/CSC-Map.cfm.
74. State Parks interview.
75. Personal communication, State Parks interviewee, November 18, 2010.
76. DNR EDO interview.
77. Personal communication from DNR EDO interviewee, November 22, 2010.
78. For further information on the status of adaptation efforts at these and other federal agencies, see the following report: Pew Center for Global Climate Change. 2010. *Climate Change Adaptation: What Federal Agencies Are Doing*. Arlington, VA, 41 pp.
79. Meeting with NPS CCRP staff and NOAA ESRL PSD research personnel, Boulder, CO, September 1, 2010.
80. NPS, 2010: *Climate Change Response Strategy*. National Park Service, September, 28 pp.
81. Smith, J. B., and W. B. Travis, 2010: *Adaptation to Climate Change in Public Lands Management*. Resources for the Future, 14 pp.
82. For a map of the Level III Ecoregions being used by BLM for the REAs, see: www.dmg.gov/documents/BR_Rapid_Ecoregional_Assessment_BLM_102809.pdf
83. For more about this index, see www.natureserve.org/prodServices/climatechange/ccvi.jsp.
84. Ford, K., 2010: "BLM Ecoregional Assessment Initiative". Presentation to *Improving the Coordination of Federal Climate and Water Resource Efforts: Focus on the Colorado River Basin*, Boulder, CO, March 18.

Multi-Agency and NGO Efforts

In 2009, The Nature Conservancy (TNC), as part of their Southwest Climate Change Initiative to provide information and tools for climate change adaptation planning and implementation, initiated a pilot study in the Gunnison River Basin. A workshop in Gunnison in December 2009 engaged researchers and managers from 20 local, state, and federal agencies and NGOs "to identify management strategies that will help native plants, animals, and ecosystems adapt to a changing climate and lay the groundwork for their implementation."[85] A follow-up workshop was held in October 2010.

In 2008, the Western Governors' Association (WGA) released the *WGA Wildlife Corridors Initiative report*, the result of a collaborative multi-state effort that developed findings and recommendations related to wildlife corridors and critical habitat. Climate change was one of five main stressors that were found to pose a risk to the integrity of ecosystems in the West, and the chapter containing the Climate Change Working Group's report presents barriers and recommendations for overcoming those barriers to achieve climate adaptation.[86]

What Does Climate Adaptation Planning Look Like in this Sector?

As described above, a number of resource agencies and other entities have recently articulated adaptation strategies to guide implementation of management for climate change. Table 4-3 lists and/or summarizes these adaptation strategies, so that common themes can be identified.

It should be noted that while climate change adaptation may require novel perspectives, data, and frameworks, it will not involve an entirely new or separate set of management tools from those already used traditionally to manage ecosystems for non-climate stressors. As DOW stated, "most of the tools used to prevent or mitigate [non-climate] threats are also applicable to addressing climate change impacts."[87] The U.S. Climate Change Science Program's 2008 review of climate adaptation options for ecosystem management echoed this, stating, "many existing best management practices for 'traditional' stressors of concern have the added benefit of reducing climate change exacerbations of those stressors."[88] That review and the more recent adaptation planning documents summarized in table 4-3 indicate that climate adaptation in this sector largely involves a reframing of existing best-practices in resource management, within a reflexive "adaptive management" framework, which can be generalized as follows:

- *Assess the vulnerabilities* of resources to climate change
- *Identify priorities* for management
- Implement management activities (mainly those already in the "tool kit") that *increase resilience* of the resources to climate change and other stressors
- *Monitor* both the impacts of climate change and the effectiveness of the management activities
- *Revise* planning and management according to the results of monitoring.

85. TNC, 2010: *Climate Change Adaptation Workshop for Natural Resource Managers in the Gunnison Basin: Summary*. Report of The Nature Conservancy, March 19.
86. WGA, 2008: *WGA Wildlife Corridors Initiative*. Report of the Western Governors' Association, June.
87. DOW interview.
88. CCSP, *Preliminary review of adaptation options for climate-sensitive ecosystems and resources*. Along these same lines, the TU interviewee observed that climate change provides "all the more reason to do what we were going to do anyway."

Table 4-3: Primary Planning Documents with Climate Adaptation Language, from Selected State and Federal Resource Management Agencies (see table 4-2.)

Agency; *Planning document with climate adaptation language*	All language pertaining to climate adaptation (DOW and CSFS) *or* Summary of key elements of climate adaptation strategy (USFS, USFWS, NPS)
DOW *Strategic Plan for 2010–2020*	- Provide analysis and recommendations to improve fish and wildlife habitats and reduce impacts from threats to those habitats (including, but not limited to, those impacts associated with energy development, climate change, urban and exurban development, and invasive species) (p. 3) - Assess climate change impacts to wildlife and habitat and develop monitoring schemes to track changes and trends in distributions and abundance of key wildlife species, as well as adaptation strategies for key species as appropriate (p. 5)
CSFS *Statewide Forest Strategy*	- [Promote] diversification of tree species mixtures and management approaches between neighboring forest stands (p. 17) - Adapt silvicultural activities to promote flexible forest response to changing climatic conditions (p. 19) - [Use] flexible and adaptive planning that considers all conceivable scenarios and multiple options for future development (p. 17) - Assess forest responses to changing climatic conditions and update forest management plans to ensure future forest viability (p. 20)

USFS
 	
National Roadmap for Responding to Climate Change
	- Develop science-based vulnerability assessments and identify potential adaptation strategies
	- Fill gaps in the knowledge base with new research
	- Use the vulnerability assessments to set priorities for adaptation
	- Implement adaptive management strategies that:
	  - build resistance to climate-related stressors (drought, fire, insects, disease)
	  - increase ecosystem resilience
	  - facilitate large-scale ecological transitions
	- Monitor climate change impacts and management effectiveness

USFWS *Rising to the Urgent Challenge*	- Develop a *National Fish and Wildlife Climate Adaptation Strategy* to guide wildlife adaptation partnerships over the next 50-100 years - Create an inventory and monitoring program to track climate change effects on the distribution and abundance of fish, wildlife and habitats; model changes in species and habitats, and assess program effectiveness - Use the LCCs to apply climate change science to conservation and build regional and field technical capacity in FWS and partner entities - Deliver conservation to the most climate-vulnerable species by identifying priority water needs, addressing habitat fragmentation, managing genetic resources, reducing non-climate stressors
NPS *Climate Change Response Strategy*	- Increase the resilience of ecosystems and support the ability of ecosystems and species to adapt to change - Conduct scenario planning to explore the range of potential conditions that parks may experience - Inventory resources at risk and conduct vulnerability assessments - Establish management guidance for applying adaptation recommendations put forward by SAP 4.4 - Prioritize and implement adaptation actions, and monitor the results

Barriers to Implementing Climate Change Adaptation and Options for Overcoming Them

The barriers to implementing effective climate change adaptation in the wildlife, ecosystems, and forests sector, as identified in the interviews, are grouped here into three categories: (1) information gaps, (2) institutional barriers, and (3) conceptual issues. It is also worth noting one barrier that was *not* mentioned in the interviews for this sector, but was identified as such in a 2010 review of public land management agencies' climate change adaptation efforts: lack of support for adaptation among the public and stakeholders.[89] The options for overcoming these challenges come from the interviews, from adaptation guidance documents consulted for this chapter, and/or from the judgment of the authors.

89. Smith and Travis, 2010: *Adaptation to Climate Change in Public Lands Management.* Public/stakeholder support was also mentioned as a barrier to adaptation in the CWCB interview; see chapter 3, Water Sector.

Information Gaps

Uncertainty Among Projections of Future Climate

The USFWS and DOW interviewees noted that the range of climate model projections for Colorado's future climate, especially with respect to precipitation, was seen as too large and thus a hindrance to planning.[90] (The TNC interviewee acknowledged the uncertainty in the projections but did not see it as a significant barrier to progress in adaptation planning.)[91] In order to support the adaptation planning contemplated by at least some agencies, the range would need to be reduced, but the climate modeling community is not optimistic that significant reductions in uncertainty will be made in the near future.[92]

Options:

- Given the uncertainty in climate projections, base vulnerability assessments and other planning on a range of plausible future climates, and implement planning frameworks that are robust to uncertain inputs.[93]
- Consult directly with climate scientists responsible for producing downscaled climate projections.

Lack of Information About Specific Climate Impacts to Colorado's Wildlife and Ecosystems

The paucity of species-level and ecosystem-level data to bridge from climate projections to projected climate impacts on wildlife species and ecosystems was cited in many interviews as a key barrier to adaptation planning. Since the capacity to quantitatively model these climate impacts, for assessing vulnerabilities, is essential to the wildlife agencies' planning strategies,[94, 95] agencies are particularly encumbered by the current lack of data. Greater understanding and quantification is particularly needed on the climatic tolerances of species.[96] The TNC interviewee stated that the current weakness in linking existing climate—let alone changed climate—to ecosystem impacts was a larger barrier than the lack of precision in climate projections.[97]

Option: Coordinate across agency lines to develop the ecological data and models to bridge from the climate scenarios to climate impacts.[98] Use the new Landscape Conservation Cooperatives (LCCs) as principal coordinating and funding mechanisms.

Unavailability of Consistent Landscape-Scale Datasets

Field observations and other data on wildlife and ecosystems have been collected and archived by myriad agencies, university researchers, and other organizations. With a few exceptions (e.g., NatureServe/ Colorado Natural Heritage Program), data sharing and synthesis has been sporadic, and seamless data across the landscape are needed.[99]

Option: Again, through active participation in the LCCs, ensure that the LCC program's strategic focus on promoting data coordination and access comes to fruition.[100]

90. This view was put forth in the USFWS and DOW interviews.
91. TNC interview.
92. A recent white paper by experts in climate modeling and adaptation concluded that improvements in regional and local climate projections over the next several years would be incremental. They caution against assuming that dramatic improvements (i.e., significant reductions in the range of projections) are forthcoming. See Barsugli, J., C. Anderson, J. Smith, and M. Vogel, 2009: *Options for Improving Climate Modeling to Assist Water Utility Planning for Climate Change*. White Paper prepared for the Water Utility Climate Alliance, San Francisco, CA, 146 pp.
93. This could be done in a more quantitative, "straight from the models" framework, such as in the Colorado River Water Availability Study (CWCB, 2010), or a more qualitative "scenario planning" approach (NPS) loosely constrained by the range of model projections.
94. USFWS interview.
95. DOW interview.
96. DOW interview.
97. TNC interview.
98. Again, the DOI's LCC program is oriented towards this goal.
99. USFWS interview.
100. DOI, 2010: Landscape Conservation Cooperatives and Climate Science Centers: Implementation Guidance. Department of the Interior, Draft Report, July 16.

Institutional Barriers

Lack of Interagency Coordination

Multiple interviewees cited the overall lack of coordination between agencies in pursuing climate change adaptation.[101] Although the preceding section enumerated many joint adaptation initiatives, the fragmented nature of the land base, conflicting institutional prerogatives, and widely varying levels of experience with adaptation planning tend to frustrate effective coordination.[102] Lack of coordination affects not just planning and management, but also the ability of agencies to share underlying data used to inform those activities.[103]

Options:

- Promote coordination among all state natural resource agencies.[104]
- Expand on the existing coordination mechanisms between state and federal agencies that have been established to deal with the MPB infestation.[105]
- Appoint a state "adaptation czar" who coordinates the state response to climate change and establishes consensus on the goals of adaptation.[106]

Inadequate Institutional Capacity

Because most of the ecosystem management agencies have only recently begun to grapple with climate adaptation on an agency-wide basis, concerns about inadequate institutional capacity were common. The DNR EDO interviewee raised the notion that the agencies in DNR may not be well suited to respond to climate change, given the range of organizational purposes.[107] The interviewee from the USFS remarked on the lack of capacity to implement climate adaptation at the level of the individual national forest.[108] In addition, in the absence of an agency-wide framework and culture supporting climate change adaptation, progress may be overly dependent on the initiative of particular individuals and then stall when those people leave the organization.[109]

Options:

- Modify governance documents and organizational structures as needed to ensure consistency with, and facilitation of, agency-wide adaptation planning.[110]
- Promote the continued information transfer from other agencies (USFS, USFWS) and entities (TNC, WAFWA) to state agencies.
- Provide the state natural resource agencies with the mandate and staff resources to actively participate in the LCCs and CSCs that cover Colorado.[111]
- Engage with the other national and regional technical resources for climate adaptation located within the state, including the USFS Rocky Mountain Research Station, the NPS Climate Change Response Program, and the Bureau of Reclamation Technical Service Center.

101. The DOW interview was particularly emphatic on this point.
102. These issues are expanded upon in Smith and Travis, 2010, *Adaptation to Climate Change in Public Lands Management*.
103. USFWS interview.
104. TNC interview. CWCB was cited as being a leader at the state level in incorporating climate change information into planning efforts.
105. USFS interview.
106. TNC interview.
107. DNR EDO interview.
108. USFS interview.
109. An example of this effect within DNR was presented in the DNR EDO interview.
110. This recommendation was not explicitly voiced in the interviews but is implicit in remarks made in the DNR EDO and TNC interviews.
111. USFWS interview.

Lack of Infrastructure and Resources

Specific to forest management, the CSFS interviewee noted that the size of the state forest products industry inhibits the range of forest treatments that can be carried out, as there is little capacity in Colorado to produce and market products from the wood generated by potential treatments.[112] In general, lack of financial resources to carry out desired planning and management is nearly always a barrier in land and resource management, and climate adaptation is no exception.[113]

Conceptual Barriers

Difficulty of Planning Given Increased Uncertainty

The DNR EDO interviewee noted, in the context of forest management, that the uncertainty around future climate is such that planners "can't operate as they are used to."[114] What they and others are used to is the range of climatic or ecological conditions described by the observed record; under climate change, this range is less relevant for future planning.

Timescales of Climate Change are Incompatible with Existing Planning and Challenges

The DNR EDO interviewee also noted that the current forest health problems in Colorado (e.g., the MPB infestation) are so severe that the operational timescales for planning and management have shrunk dramatically,[115] inhibiting the long-term outlook needed to address climate change. Projected changes in climate and their impacts are expected to fully manifest over several decades and longer, suggesting the need for planning horizons longer than those typically used by resource management agencies (e.g., 10-year DOW strategic plans).

Option: Carry out informal planning exercises that consider the impacts of climate change on managed resources 20-50 years out.

Additional Options for Facilitating Climate Adaptation for Wildlife, Ecosystems, and Forests

- Encourage the development of adaptation planning frameworks by state agencies that are consistent with those recently developed by the federal resource management agencies (table 4-3) and the guidance from multi-agency[116] and other synthesis reports[117] on adaptation strategies.[118]

- Develop a statewide ecosystem/species vulnerability assessment so that adaptation priorities can be set, in coordination with the federal agencies currently pursuing vulnerability assessments within Colorado. [119, 120]

- Monitor the effects of the adaptation strategies that are implemented and adjust strategies as needed (i.e., "adaptive management").[121]

- Promote integrated resource management and adaptation planning at the landscape/basin scale (e.g., the Gunnison Basin pilot study) rather than the statewide scale or by jurisdiction.[122]

112. CSFS interview. "Forest treatments" in an adaptation context means the harvesting of trees to change forest conditions (density, species mix, fuel structure, etc.) to enhance resilience to climate change and other stressors.
113. Smith and Travis, 2010: *Adaptation to Climate Change in Public Lands Management.*
114. DNR EDO interview.
115. DNR EDO interview.
116. E.g., CCSP, *Preliminary review of adaptation options for climate-sensitive ecosystems and resources*.
117. E.g., The Heinz Center, 2008: *Strategies for Managing the Effects of Climate Change on Wildlife and Ecosystems*. The H. John Heinz III Center for Science, Economics, and the Environment, November, 42 pp.
118. The DOW interview indicated that DOW is currently working along these lines in their preparation for the update of the SWAP.
119. DOW interview.
120. TNC interview.
121. DOW interview.
122. TNC interview.

- Engage private landowners, who own and manage 60 percent of the state's land base, in climate adaptation, whether through existing programs administered by CSFS, DOW, and CWCB that support conservation measures by private landowners, or through new programs.
- When selecting and implementing mitigation strategies, consider any impacts to adaptive capacity; for example, new alternative energy infrastructure that might reduce the resilience of ecosystems.

5 Electricity Sector in Colorado

Key Points

- The electricity sector in Colorado is a complex mix of investor-owned utilities, rural electric associations, and municipal utilities. The Public Utilities Commission (PUC) and the Governor's Energy Office (GEO) are the two primary state-level entities with regulatory and policymaking authority for this sector, although several other state and federal agencies also play important roles.

- Electric utilities in Colorado face a number of climate-sensitive challenges that could be exacerbated by future warming. These challenges include meeting short-term peaks in demand often caused by the need for summertime space cooling; providing water supplies to water-cooled generation units, especially coal-fired power plants; and adapting to impacts of policies and technologies designed to reduce greenhouse gas emissions, including carbon pricing mechanisms and electric vehicles.

- Electric utilities and state agencies already possess significant adaptive capacity through the electric resource planning process, which requires utilities to plan for long-term shifts in demand. Utilities are also accustomed to using a variety of mechanisms to accommodate significant short-term peaks in demand, although current mechanisms are relatively inefficient. Demand response and dynamic metering mechanisms such as the new SmartGridCity offer significant promise for increasing future adaptive capacity in the electricity sector.

- The difficulty of siting new transmission lines to bring renewable power from areas of high potential generation to areas of high demand is a significant barrier currently facing the sector, as is uncertainty about the impact of increased penetration of renewable generation resources.

- Options for facilitating adaptation in the electricity sector include promoting additional research on integrating renewable resources in the grid, giving the PUC a more proactive role in directing utilities to incorporate additional renewables, and tying adaptation and mitigation measures to economic development.

Although a great deal of discussion about the electricity sector revolves around its greenhouse gas emissions, climate variability and change can have serious impacts on the generation and distribution of electric power needed to keep Colorado's economy running. This chapter provides a brief overview of electricity generation and distribution in Colorado. It then discusses possible impacts along with current and planned adaptation efforts considered by various stakeholders throughout the state.

Overview of Electricity in Colorado

Generation and Consumption

Overall, energy in Colorado is used for three main purposes—transportation, heating, and electricity production. The state consumed 94.1 million barrels of petroleum in 2008, largely to power motor vehicles and airlines. Two-thirds of homes in Colorado get their heat from natural gas, with much of the remainder coming from electricity.[1] Natural gas service is provided by 14 utilities across the state, including six investor-owned utilities and eight municipal utilities.[2]

Colorado's electricity is almost entirely generated from fossil fuels. Coal is the largest source, powering 57 percent of the 61 million megawatt-hours produced in the state in 2009. Natural gas fueled 27 percent of the state's electricity generation, with the remainder coming largely from renewable sources such as wind and solar (7 percent) and hydroelectric power (5 percent).[3] Colorado does not have any nuclear power plants.

Passage of recent state legislation, HB10-1365 (the Clean Air-Clean Jobs Act), is likely to significantly reduce coal consumption in Colorado. The bill requires Xcel Energy, the state's largest electric utility, to retire or retrofit 900 megawatts of coal-fired power plants along the Front Range in order to reduce nitrogen oxide emissions by at least 70 percent from the year 2008 baseline.[4] Although the legislation does not mandate a specific generation mix to meet these goals, it will likely lead to a significant increase in natural gas consumption for electricity generation.

Structure and Regulation of Electricity Supply

Colorado has a regulated electric market, meaning that the state did not deregulate electric utilities as many others did during the late 1990s.[5] The electricity industry in Colorado is a complex mix of public, non-profit, and for-profit entities. Much of the electricity generation capacity in the state is owned or generated by Xcel Energy, notable for being the nation's largest utility provider of wind energy. A number of wholesale power producers, including Tri-State Generation and Transmission Association, Inc., and the federal Western Area Power Administration, part of the U.S. Department of Energy, generate the remainder of the state's electricity.[6]

Retail sales of electricity are handled by three types of entities: investor-owned utilities, municipal utilities, and rural electric associations. Investor-owned utilities (IOUs) are publicly-traded for-profit companies. The state's two IOUs serve 63 percent of the state's customers—1.4 million by Xcel Energy and

1. U.S. Department of Energy, Energy Information Agency (EIA), 2010: *Colorado State Energy Profile*. [Available online at www.eia.doe.gov/state/state_energy_profiles.cfm?sid=CO, accessed October 22, 2010.]
2. Colorado Governor's Energy Office (GEO), 2010: *2010 Colorado Utilities Report*. [Available online at rechargecolorado.com/images/uploads/pdfs/2010_Colorado_Utilities__Report.pdf.]
3. 2010 *Colorado Utilities Report.*
4. GEO interview.
5. The Colorado Electricity Advisory Committee, created by state law in 1998, considered and ultimately voted against deregulating the state's electric sector. For more information, see "Colorado Restructuring not Active," www.eia.doe.gov/cneaf/electricity/page/restructuring/colorado.html.
6. 2010 *Colorado Utilities Report.*

600,000 by Black Hills Energy. Twenty-nine municipalities across the state operate their own municipal utilities. Twenty-six rural electric associations (REAs), most of which were set up after the establishment of the federal Rural Electrification Administration in 1935, serve the remainder of the state's customers.[7]

Given the complexity of electricity generation and sales in the state, the regulatory environment is rather convoluted. The state Public Utilities Commission (PUC) has ratemaking and generation regulatory authority over the state's two IOUs. The PUC has limited authority on generation and transmission approvals for Tri-State Generation and Transmission, which provides power to most of the REAs. The REAs themselves are member-owned and governed by cooperative boards and report to the U.S. Department of Agriculture's Rural Utilities Service. Municipal utilities, on the other hand, are governed by their respective municipalities. The PUC has no authority to regulate either municipal utilities or REAs, both of which are required to follow state law but are essentially self-regulating. State law, in some instances, applies one set of requirements to REAs and municipal utilities and a different set to IOUs, as was the case with Amendment 37, which created Colorado's renewable energy standard.

The PUC, part of the state Department of Regulatory Agencies, serves as a regulatory body operating through a quasi-judicial system. The commission sees itself as a "balancing agent," sorting through the concerns of all interested parties to ensure the continued economic viability of the investor-owned utilities while also ensuring that utility customers pay fair rates for electricity.[8] Through its electric resource planning (ERP) process, the PUC oversees load forecasting and generation planning at IOUs. While Tri-State is required to file an ERP with the PUC, the commission does not have the authority to approve or deny the plan, only to issue a Certificate of Public Convenience and Necessity for transmission and power plant siting requests from Tri-State. The PUC rarely interacts on a formal basis with municipal utilities and REAs, the exception being planning for transmission infrastructure.[9] The PUC interviewee noted that REAs "don't like to be in the same room as the commission."[10]

The PUC interviewee also emphasized that the PUC itself does not advocate for or set specific energy policies. Instead, both the state legislature and the Governor's Energy Office (GEO) are responsible for setting state energy policy.[11] The state legislature generally deals with broader issues, such as HB 1001, which increased to 30 percent the requirement that IOUs produce a certain percentage of their electricity from renewable sources, and HB 1365, the Clean Air-Clean Jobs Act described earlier. State legislators also refer specific questions to the public ballot, as was the case with the original renewable energy standard passed in 2004 as Amendment 37.[12]

GEO is formally part of the governor's administrative office, operating at the discretion of the administration and working to carry out the governor's energy agenda.[13] GEO, originally created in 1977, was re-created in 2007 by Governor Bill Ritter, Jr. with the mission of advancing renewable energy and energy efficiency across the state,[14] which it does mainly by administering incentive programs and conducting studies and analyses aimed at understanding energy-related challenges across the state. While GEO's work is directly related to greenhouse gas mitigation, it also considers the impacts of climate on the energy sector, notably changes in the availability of water needed for electricity generation.[15]

The Colorado Department of Public Health and Environment (CDPHE) also plays a significant role in Colorado's energy sector, primarily through permitting of fossil fuel-based power plants.[16] Under the federal Clean Air Act, major stationary sources of pollution require permits for construction and operation, which in Colorado are issued by CDPHE. The department also issues water quality permits for plants that discharge used water directly into surface water bodies.

7. 2010 *Colorado Utilities Report*.
8. PUC interview.
9. PUC interview.
10. PUC interview.
11. PUC interview.
12. More information on the legislative history of Colorado's renewable energy standard is available online at www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=CO24R.
13. PUC interview.
14. "Who is the GEO?" web page. [Available online at rechargecolorado.com/index.php/who_is_the_geo/, accessed November 10, 2010.]
15. GEO interview.
16. PUC interview.

Finally, a number of smaller regulatory and policymaking bodies play various roles in Colorado's electricity sector. The Office of the State Engineer, part of the Department of Natural Resources, permits geothermal wells on state and private lands and consults for courts on water rights issues related to the permitting of hydropower facilities in the state.[17] The Federal Energy Regulatory Commission permits large hydropower facilities, while renewable energy resources placed on federal lands are permitted by various agencies depending on the type of land involved. Most of Colorado's electric utilities are part of the Western Electricity Coordinating Council, which is responsible for coordinating bulk electric system reliability and promoting open interstate transmission access throughout the grid known as the Western Interconnection.[18]

Interviews and Sources for This Chapter

The CCPP research team conducted three interviews for the electricity sector—one with the Governor's Energy Office, one with the Public Utilities Commission, and one with representatives of Xcel Energy. These interviews informed the discussions below of adaptation actions and potential impacts. Consistent with other chapters, we consulted major assessments from the U.S. Global Change Research Program (formerly known as the Climate Change Science Program) and the Intergovernmental Panel on Climate Change for additional information on impacts.

At the suggestion of Xcel Energy's representatives, we considered the company's 10-K report, a risk disclosure report filed with the Securities and Exchange Commission, as a supplement to our interview with the utility. Unlike many other sectors, there are very few reports detailing specific impacts or adaptation options in the electricity sector, excluding discussions of climate mitigation efforts. One product of note that may be useful to readers of this chapter is GEO's 2010 Colorado Utilities Report.[19]

Note that, due to time restrictions, we were unable to interview REA or municipal utility representatives.

Potential Climate Impacts to Colorado's Electricity Supply

Because the burning of fossil fuels to produce energy is responsible for most human-caused sources of greenhouse gas emissions, a significant body of scientific research has focused on the electricity sector's role in driving climate change. Comparatively less research has focused on the impacts of a changing climate on electricity production and delivery, but this sector still faces potentially significant climate impacts.

This chapter relies on *Effects of Climate Change on Energy Production and Use in the United States*, published in 2007 by the U.S. Climate Change Science Program,[20] along with *Global Climate Change Impacts in the United States*, published by the U.S. Global Change Research Program in 2009.[21] We also consulted Section 7.2.4.1 of Working Group II of the 2007 Fourth Assessment Report compiled by the Intergovernmental Panel on Climate Change (IPCC),[22] although that report contained significantly less relevant detail compared to the CCSP and USGCRP reports. Combined with descriptions of potential impacts from CCPP interviews, we used these sources to compile a brief overview of potential climate-related impacts to Colorado's electricity supply.

17. State Engineer interview.
18. For more information, see www.wecc.biz/About/Pages/default.aspx.
19. [Available online at rechargecolorado.com/images/uploads/pdfs/2010_Colorado_Utilities__Report.pdf.]
20. CCSP, 2007: *Effects of Climate Change on Energy Production and Use in the United States*. A Report by the U.S. Climate Change Science Program and the subcommittee on Global Change Research. Wilbanks, T.J., V. Bhatt, D. E. Bilello, S. R. Bull, J. Ekmann, W. C. Horak, Y. J. Huang, M. D. Levine, M. J. Sale, D. K. Schmalzer, and M. J. Scott, eds. U.S. Department of Energy, Office of Biological & Environmental Research, Washington, DC, 160 pp. [Available online at www.globalchange.gov/publications/reports/scientific-assessments/saps/sap4-5.]
21. USGCRP, 2009: *Climate Change Impacts in the United States*, Karl, T.R., J.M. Melillo, T.C. Peterson, S.J. Hassol, eds., U.S. Global Change Research Program, Washington, DC, 53-60. [Available online at www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/climate-change-impacts-by-sector/energy-supply-and-use.]
22. Wilbanks, T.J., P. Romero Lankao, M. Bao, F. Berkhout, S. Cairncross, J.-P. Ceron, M. Kapshe, R. Muir-Wood and R. Zapata-Marti, 2007: "Industry, settlement and society." *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 357-390. [Available online at www.ipcc.ch/publications_and_data/ar4/wg2/en/ch7.html.]

Physical Impacts

Table 5-1 lists the major findings of the CCSP and USGCRP reports that apply to Colorado's electricity sector. Note that although there is a significant body of research aimed at understanding climate change impacts on energy consumption in buildings, many of the other impacts listed below have not been studied in depth.

Table 5-1

Potential climate impacts on Colorado's electricity supply.[23] Impacts listed in *italics* were addressed by interviewees.
Changes in Energy Consumption Patterns
• Rising winter temperatures are expected to reduce the need for residential and commercial heating, decreasing overall wintertime demand for natural gas.
• *Rising summertime temperatures, along with increasing population and greater use of air conditioning, are expected to increase demand for electricity and force utilities to build additional peak generation capacity.*
• Overall, energy consumption is expected to decrease as the need for winter heating declines, but overall electricity consumption will increase as installation and use of air conditioning increases.
• *Climate change is expected to compound the impacts of overall trends in energy consumption, which have seen increased efficiency in heating and cooling but steady growth in energy use due to increasing overall plug loads.*
• Increasing water scarcity is expected to increase demands for energy needed to pump water throughout the state.
Physical Impacts to Energy Supply and Energy Infrastructure
• *Reductions in water supply from changes in precipitation and snowpack are expected to increase competition for water among various industries, including the energy sector.*
• *Water shortages and higher water temperatures are expected to limit production and efficiency at water-cooled electric generation stations.*
• Increased ambient temperatures are expected to reduce both efficiency and overall power output at natural gas-fired power plants.
• *Increased frequency of severe weather events, including windstorms, wildfires, and heat waves, are expected to affect the reliability of the electricity grid.*
• Changes in precipitation, stream runoff, and many other climate-related factors are expected to affect efficiency of hydroelectric generation facilities.
• Changes in cloud cover are expected to affect the efficiency of solar energy resources.
• Changes in wind patterns, wind speeds, and intermittency are expected to affect the efficiency of wind turbines and its incorporation into the electric grid.[24]
• Reductions in water availability and changes in the frequency of extreme events are expected to affect the production and distribution of fossil fuel resources, potentially affecting electricity generation and price.

Of these potential impacts, the possibility of hotter summers is likely to have the most significant negative impact on Colorado's electricity generation and distribution infrastructure. The U.S. electricity system is currently built to have adequate capacity to meet the highest peak demand at any given point during the year, usually hot summer afternoons when the use of air conditioning is greatest. Thus, Colorado utilities would potentially have to build and maintain generation facilities that are often inefficient and rarely used solely to meet the additional peak demand from increased air conditioning usage. Xcel Energy noted that increased demand could increase the need for new generation and affect system operations, but that cool summers and mild winters could also negatively affect the company by reducing overall revenues and impacting the utility's financial stability.[25]

23. Adapted from 2007: *Effects of Climate Change on Energy Production and Use in the United States and 2009: Climate Change Impacts in the United States*.
24. The state climatologist interviewee noted that variable winter wind patterns have already rendered certain wind power installations in Colorado nearly useless during certain years.
25. Xcel Energy (as Public Service Company of Colorado), March 3, 2010. U.S. Securities and Exchange Commission Form 10-K. [Available online at phx.corporate-ir.net/phoenix.zhtml?c=89458&p=irol-sec.]

Future changes in the frequency or intensity of extreme weather events could have significant impacts on the electricity sector. Extreme events such as windstorms, snowstorms, and wildfire require additional system backup and increase the costs of providing service and restoring damaged infrastructure. Xcel Energy in particular is concerned about potential impacts from future extreme weather events.[26]

In addition, interviewees all agreed that water supply concerns affect the operation and siting of power plants that rely on water for cooling, including certain types of coal, natural gas, and concentrating solar power facilities.[27] Water scarcity is a significant concern in Colorado, and future discussions of water supply are more likely to integrate discussions of energy supply throughout the state.

Although climate can significantly impact hydroelectric generation facilities, hydropower is not a significant resource overall in Colorado.[28] As noted earlier, hydropower accounts for only 5 percent of the state's electricity supply, and both mountainous terrain and administrative difficulties make it unlikely that additional significant hydropower stations will be built in Colorado,[29] apart from small "micro hydro" generation.[30] Interviewees at Xcel Energy emphasized that the only significant hydropower resource on their system is the Cabin Creek pumped hydropower plant in Georgetown, which pumps water uphill at night and releases it downhill during the day to provide peak power as needed.[31]

Interviewees also expressed concerns about possible climate-related impacts on electricity generation from renewable sources. Photovoltaic and concentrating solar power, both of which have been built or are under consideration across Colorado, work best under clear, sunny skies. Changes in cloud cover and snow patterns can affect the efficiency of solar resources by reducing or eliminating solar radiation reaching the generation facilities. Similarly, changes in wind patterns could affect the efficiency of wind power generation. Little research has been done to understand or quantify these effects.[32]

Impacts of Climate Mitigation Efforts

All electricity sector interviewees emphasized that some of the most significant potential impacts of climate change on the operation of Colorado's electric grid will result from new initiatives and regulations related to greenhouse gas mitigation and clean energy standards. Although renewable sources already comprise a growing percentage of electric generation across the state, regulators and utilities are concerned about the ability to maintain a reliable grid as use of these intermittent resources increases.[33]

As a new wave of electric vehicles (EVs) begins to arrive on the consumer market, the electric power industry is concerned about the impacts that a major shift in transportation energy use could have on the electric grid.[34] Widespread adoption of EVs could place a significant new burden on electricity demand[35] during off-peak hours for nighttime charging and intermittently during the day for on-peak charging. EVs could expose distribution systems, such as transformers, to overloaded demand curves if customers choose to charge their vehicles during summer peak times.[36]

The PUC noted that additional efforts to reduce carbon emissions from electricity generation would likely increase pressure on system reliability, retail rates, and the ability of investor-owned utilities to maintain financial stability in the face of various policies aimed at climate mitigation.[37] Xcel Energy's representatives advocated that new greenhouse gas reduction policies be flexible enough for them to implement without serious financial impacts for both the company and its customers.[38] They also noted that if carbon pricing were to affect the price of goods and services in their service territory, they could

26. Xcel Energy 10-K.
27. GEO, PUC, Xcel interviews.
28. GEO, Xcel interviews.
29. Xcel interview.
30. State engineer interview.
31. Xcel interview.
32. GEO interview.
33. PUC, Xcel, and GEO interviews.
34. GEO interview.
35. Xcel interview.
36. GEO interview.
37. PUC interview.
38. Xcel interview.

face negative financial performance.[39] Although many of these comments are directed at the financial performance of a private company, both the PUC and Xcel emphasized that financial performance of the utility is tied to system reliability and retail electric rates.[40]

Finally, interviewees raised concerns about the impacts of rapid technology change[41] and future climate-related legislation[42] on the traditional utility business model as implemented in Colorado. Xcel in particular is significantly concerned about uncertainties in the future regulatory environment, including the impacts of greenhouse gas mitigation policies. Xcel strongly favors a unified federal policy on greenhouse gases over state or other policies.[43]

Current and Planned Adaptation Efforts

In general, regulators and others interviewed for the electricity sector are not actively developing climate adaptation plans. However, it appears that climate concerns are being incorporated into long-term planning efforts and are clearly an important part of management decisions in an industry keenly aware of its role in producing greenhouse gas emissions responsible for climate change.

Existing Adaptive Capacity

Investor-owned utilities can incorporate climate concerns into planning through electric resource plans (ERP) submitted every four years to the PUC. Prior to beginning this process, utilities prepare electric energy and demand forecasts demonstrating expected changes in generation capacity and electricity demand. These forecasts include base, high, and low cases, providing scenarios that the PUC uses in evaluating a utility's ERP proposal. Demand baselines are based upon past experience combined with population and economic projections. In addition, sensitivity analyses incorporated into demand forecasts allow the utility and the PUC to consider alternative future scenarios involving more or less summertime demand for cooling, population growth, and other conditions.[44] The PUC interviewee pointed to these forecasts as a mechanism for incorporating climate change into the ERP process, since forecast scenarios could "include projections of climate-change-related energy uses, such as space conditioning (air conditioning) and agricultural water pumping."[45]

Utilities use electric energy and demand forecasts to develop ERPs, which describe how they intend to arrange existing and future generation resources, including sufficient safety margins, to meet the forecasted load during the 10–20 year planning horizon. In 2007, Xcel Energy incorporated the effects of a potential carbon price for the first time in an ERP.[46] The PUC does not explicitly require IOUs to incorporate specific renewable resources or other carbon reduction strategies into ERPs. However, the commission does analyze the potential for climate impacts and carbon pricing schemes to affect the continued provision of reliable and fairly priced electricity.[47] Additionally, the IOUs are required by statute to meet the 30 percent renewable energy requirement by the year 2020. These resources are outlined in the IOUs' renewable energy compliance plans.

Utilities in Colorado and elsewhere across the country use a variety of strategies to meet summer peak demands for electricity. For example, Xcel Energy relies on its Cabin Creek pumped hydropower plant to provide inexpensive peak daytime power rather than relying on more expensive fossil fuel-based resources.[48] Variable-rate pricing schemes, including Xcel Energy's new tiered residential pricing scheme, allow utilities to send a price signal to consumers aimed at reducing or shifting peak electricity usage.[49]

39. Xcel Energy 10-K.
40. Xcel and PUC interviews.
41. PUC interview.
42. GEO and Xcel interviews.
43. Xcel interview.
44. As noted by PUC interviewee, these forecasts are required under PUC rule 3606. [Available online at www.dora.state.co.us/puc/rules/723-3.pdf.]
45. PUC interview.
46. PUC interview.
47. PUC interview.
48. Xcel interview.
49. PUC interview.

The tiered rate program builds on existing Xcel Energy programs such as Saver's Switch, which allows the utility to turn off air conditioning units as needed, and the Interruptible Service Option Credit, which pays businesses to allow the utility to shut off their power in times of extreme system stress.[50]

As is common practice across the country, the PUC requires its regulated utilities to incorporate safety margins into planning and operations to ensure system stability and prevent power outages in the event of unexpected stresses or shocks to the system, such as extreme weather, failure of a large power plant, or sudden changes in demand.[51] The total reserve available is known as the planning reserve margin, expressed as a percentage of total peak system capacity. A portion of the planning reserve margin is held as spinning reserve, defined as generation resources capable of coming online and providing power within ten minutes. Xcel Energy's total planning reserve margin is currently 16 percent.[52]

During normal conditions, reserve margins represent a significant inefficiency in both development and operation of generation resources. "The problem with the grid is that it's overbuilt and designed to be robust," an Xcel Energy representative noted.[53] In an attempt to reduce these inefficiencies, Xcel Energy has pursued a number of dynamic metering initiatives aimed at better understanding peak demand and providing the utility with the ability to potentially reduce demand at specific times. In the words of the Xcel Energy representative, "dynamic metering gives the potential to better match supply and demand."[54] The most sophisticated effort to pursue dynamic metering is Xcel Energy's pilot SmartGridCity program unveiled in 2008 in Boulder. According to Xcel Energy, SmartGridCity is largely an information tool and can be useful in terms of both climate adaptation and climate mitigation. It offers customers significant information about their consumption habits while providing the utility with significant data about changes in usage patterns that could be useful, for example, in deferring future power plant technology.[55] Partly due to unexpected costs associated with SmartGridCity, Xcel Energy now believes it is unlikely they will pursue such a sophisticated system in another area, but contends that various types of dynamic metering and demand response are likely to expand across their service territory.[56]

Planned Adaptation Efforts

In addition to contemplating more widespread implementation of dynamic metering and demand response, utilities, regulators, and policymakers are considering a number of options that would, in effect, reduce overall system vulnerability to climate impacts, especially future water scarcity.

Although HB10-1365, the Clean Air-Clean Jobs Act passed in 2010, will have a much more significant impact on air quality than on carbon emissions,[57] it is essentially both a climate mitigation and adaptation tool.[58] In addition to reducing the use of coal, the most carbon-intensive fuel used in electric power production, HB10-1365 will also reduce water use by encouraging greater use of natural gas-fired power plants that require less water for cooling.[59] Xcel believes HB10-1365 is "a good example of regulation that provides flexibility because it allows Xcel to create its own plan rather than having everything dictated to them on a stack-by-stack basis."[60]

All three electricity sector interviewees emphasized the need to adapt to a future in which electricity production is affected by increasing constraints on water supplies. The PUC noted that bids given to

50. PUC interview.
51. PUC interview.
52. Xcel interview.
53. Xcel interview; GEO interview also noted that current grid is inefficient.
54. Xcel interview.
55. PUC interview.
56. Xcel interview. For more information about Smart Grid efforts in Colorado, there are two reports available in the CCPP database: "Deploying Smart Grid in Colorado: Recommendations and Options," authored by the Colorado Smart Grid Task Force, and "Smart Grid Deployment in Colorado: Challenges and Opportunities," produced by the University of Colorado at Boulder.
57. PUC interview.
58. GEO interview.
59. GEO interview.
60. Xcel interview; the phrase "stack-by-stack" refers to regulations that would dictate emission requirements for each specific power plant operated by the utility.

IOUs to purchase electricity from new power plants must describe where the plant's owners intend to get water for operations and how much it will cost to secure the necessary water rights.[61] Likewise, Xcel considers water availability and water prices in planning new power plants.[62] "Future water use from population growth is incorporated into energy demand forecasts," an Xcel interviewee noted.[63] GEO indicated that they are considering ways to diversify the state's energy portfolio to advance low water consumptive technologies, which has already factored into the state's efforts to increase requirements for renewable energy. GEO is also updating the state's energy emergency plan and including water availability components. Perhaps the most sophisticated effort to anticipate water and energy concerns is an ongoing GEO-funded study by researchers at Colorado State University who are investigating how to promote energy outcomes such as low carbon emissions and low water consumption without promoting specific generation technologies.

Other potential adaptation mechanisms mentioned by interviewees but not discussed in depth included the possibility of improving transmission ties across the West, which would allow power to move more freely in times of stress and potentially improve overall system stability.[64] In addition, GEO and Xcel Energy are working on a study to evaluate the benefits of distributed solar generation to the utility's system.[65]

Barriers to Adaptation

Interviewees identified both information and regulatory barriers that pose impediments to adaptation in Colorado's electricity sector.

Information Gaps

Key among concerns expressed by interviewees was the uncertainty surrounding specific scientific questions. Xcel Energy's representatives noted that "climate change science is still dramatically uncertain" and expressed frustration at ongoing scientific debates about the issue.[66] The PUC also expressed concern that increased variability due to climate change may be difficult to incorporate into load forecasting.[67]

Another significant information gap appears to be the lack of research on how climate variability and change might affect renewable energy production. GEO representatives expressed concerns about the possibility that climate change could affect wind patterns, potentially reducing the efficiency of wind turbines, or could reduce the efficiency of photovoltaic solar systems through increased temperatures, but acknowledged the lack of research into those questions.[68]

Finally, understanding the impacts of intermittent renewable energy sources, electric vehicles (EVs), and other clean energy initiatives to the electric grid remains an information gap. Xcel representatives said they have already adapted to having more than 1,200 megawatts of wind power on their grid, but expressed concerns about the impact of additional renewable resources as well as major new demands like EVs.[69] GEO shared similar concerns, noting in addition that load shifting from demand response could potentially drive increased generation from coal-fired power plants,[70] a concern partly addressed in the "Smart Grid Deployment in Colorado" report available in the CCPP database.

Institutional Barriers

Increasing generation from renewable energy resources could potentially help utilities adapt to future climate mitigation efforts by reducing vulnerability to carbon pricing and changing fossil fuel prices.

61. PUC interview.
62. Xcel interview.
63. Xcel interview.
64. PUC interview.
65. GEO interview.
66. Xcel interview.
67. PUC interview.
68. GEO interview.
69. Xcel interview.
70. GEO interview.

However, existing barriers complicate efforts to create additional renewable generation. According to GEO, the biggest barrier to deploying more renewable energy resources is the lack of high voltage transmission to effectively deliver utility scale renewable energy to the electric load centers.[71]

Option: Siting transmission lines is a highly politically charged process, so options related to this barrier are beyond the scope of the report.

Macroeconomic factors can impact whether renewable energy resources are included in resource plans because economic stagnation tends to reduce demand for electricity, eliminating the need for new generation resources.[72] The PUC interviewee emphasized additional barriers to renewable deployment, including the intermittency of most renewable energy sources and "the inability to reasonably restructure the generation resource analysis/comparison process . . . to an extent that would yield more renewables coming out of the ERP process."[73] According to the interviewee, the current ERP process does not adequately incorporate non-economic benefits of renewables, such as environmental benefits.[74]

Option: State statutes or PUC rules could be amended to more proactively factor climate change adaptation into regulated utility resource planning, such as giving more weight to clean technologies in the selection of electric generation resources.[75]

GEO also described the "bifurcation" of the energy system in Colorado as a barrier to greater integration of renewable resources into the grid.[76] As noted earlier, only IOUs are regulated by the Public Utilities Commission, not the REAs or municipal utilities that serve nearly half the state's customers. Having one set of utilities regulated directly by a state agency and another set of utilities much less constrained by state-level regulations makes it difficult to deploy statewide adaptation options. Although REAs vary widely in their attitudes towards participating in climate mitigation or adaptation efforts, they are generally reluctant to engage in any activities that might interfere with servicing the rural electric service loans they hold from the U.S. Department of Agriculture.[77]

Option: GEO could use its position to facilitate cooperation among IOUs, rural electric associations, and municipal utilities to help increase renewable deployment and promote efforts to understand climate vulnerabilities across the state's energy sector.

GEO did point out that the Ritter administration has "brought down silos" within state government, allowing agencies to work together better. The energy office has been able to work on climate issues with a host of other agencies, including the Department of Public Health and Environment, the Department of Labor and Employment, the Department of Local Affairs, and the Department of Transportation.[78] GEO noted, however, that working on climate issues with Colorado Department of Transportation (CDOT) is hampered by the fact that the transportation department has few resources to spare beyond what it devotes to maintaining the state's transportation infrastructure.[79]

Option: GEO could use its role as a direct arm of the governor's administration to facilitate energy-related adaptation efforts across multiple state agencies.

The PUC pointed to public perceptions of energy supply and pricing as a significant barrier to deploying adaptation options such as tiered pricing. Many ratepayers believe that Xcel's recent introduction of a residential tiered pricing structure is essentially a rate increase, even though it is aimed at putting more of the financial burden of peak generation on customers responsible for creating peak demand.

71. GEO interview.
72. PUC interview.
73. PUC interview.
74. PUC interview.
75. PUC interview.
76. GEO interview.
77. PUC interview.
78. GEO interview.
79. GEO interview.

Option: GEO, the PUC, and utilities could work together to further educate the public about the benefits of tiered pricing and other variable rate structures that could be useful as climate adaptation mechanisms.

Xcel Energy noted specific legal and regulatory constraints that hamper their ability to adapt or move toward a lower carbon emissions profile. The utility values the energy storage capacity of their Cabin Creek pumped hydroelectric plant, which helps deal with summer peak demands expected to increase in a hotter future, and would like to build additional ones. However, permitting and building new ones is "nearly impossible" due to both the need for access to mountainous terrain and the regulatory burden of getting permits for new hydropower facilities.[80] Siting for other renewable energy sources, such as wind turbines, is also becoming more difficult. Xcel Energy's representatives noted the extraordinary difficulty of obtaining the multitude of permits necessary to build new transmission lines, especially to bring power from areas well suited for renewable resources to areas with high demand for electricity.[81] The current controversy over building a transmission line to deliver power from a proposed solar project in the San Luis Valley illustrates this potential barrier.

Option: State agencies could work together to develop a more comprehensive framework for integrating renewable energy development into land management and planning.

Xcel Energy's representatives also repeatedly emphasized the need for flexibility in climate regulations to allow the utility to meet new obligations without substantial financial burden. The utility favors the flexibility of HB10-1365, which sets a target and allows the utility to decide how to comply, rather than the more formal structure of the federal Clean Air Act, which requires utilities to meet plant-by-plant pollution restrictions. They also emphasized the need for regulators to allow the utility to recover costs from new regulations, allowing them to remain financially sound.[82] Overall uncertainty about the future of climate regulations, especially from the federal level, poses a significant risk to Xcel Energy's financial stability.[83]

Option: The state could advocate for the inclusion of flexible, market-based mechanisms in federal greenhouse gas legislation.

Facilitating Adaptation in Colorado's Electricity Sector

The electricity sector in Colorado, already accustomed to planning for an uncertain future, appears to have tremendous capacity to adapt to climate variability and change. However, this sector also faces a unique challenge—adapting not only to the impacts of climate itself but also to the impacts of regulatory efforts to mitigate climate change. From our review of impacts and the interviews conducted for this sector, we suggest that a state adaptation plan could take advantage of existing adaptive capacity and facilitate existing efforts to make the state's electric grid more resilient in the face of future climate impacts.

Options for elements of a state adaptation plan in the electricity sector are summarized in table 5-2. Those provided directly by interviewees are listed in italics.

80. Xcel interview.
81. Xcel interview.
82. Xcel interview.
83. Xcel Energy 10-K.

Table 5-2

Options for a state adaptation plan in the electricity sector
Research
• *State agencies and utilities could promote or conduct research aimed at understanding how to accommodate greater penetration of renewable energy resources into Colorado's electricity grid, such as an ongoing GEO study examining the grid impacts of increased use of distributed generation such as rooftop photovoltaic systems, as suggested by GEO.*[84]
• The state could conduct a vulnerability assessment to determine whether current adaptive capacity in the electricity sector is capable of meeting future climate challenges along with the impacts of climate mitigation efforts.
• Xcel Energy, GEO, and the PUC could examine the recommendations from the governor's Colorado Smart Grid Task Force, along with Xcel's experiences with the SmartGridCity Project, and apply lessons learned to future efforts to incorporate demand response into utility planning.
• GEO could work with Colorado universities, the National Renewable Energy Laboratory, and others to promote research into the impacts of climate change on renewable energy generation.
• GEO could continue to promote cutting-edge research on emergency planning and climate mitigation impacts on the electricity sector.
Policy and Regulatory Options
• *The state should consider the merits of amending state statutes or PUC rules to more proactively factor climate change adaptation into regulated utility resource planning, such as giving more weight to clean technologies in the selection of electric generation resources, as suggested by the PUC.*[85]
• *The state should consider the merits of developing new laws and regulations pertaining to carbon emissions or other pollutants using flexible market mechanisms and designed to allow Xcel Energy to adequately recover the costs of compliance, as suggested by Xcel.*[86]
• GEO could use its role as a direct arm of the governor's administration to facilitate energy-related adaptation efforts across multiple state agencies.
• State agencies and utilities could work to develop climate mitigation options that best fit Colorado's electricity supply structure in order to promote system stability and avoid rate spikes due to regulatory compliance costs.
• GEO could use its position to facilitate cooperation among IOUs, rural electric associations, and municipal utilities to help increase renewable deployment and promote efforts to understand climate vulnerabilities across the state's energy sector.
• The state could advocate for the inclusion of flexible, market-based mechanisms in federal greenhouse gas legislation.
Planning
• State officials could carefully consider the cross-cutting impacts of climate on both water and energy supplies and look to reduce water consumption in the electricity sector.
• State agencies could expect continued pressure to reduce carbon emissions from the electricity sector and should work hand-in-hand with utilities and generation companies to prepare for the impacts of greater use of renewable resources, electric vehicles, and other technologies on grid stability.
• State agencies could quantify the benefits of expanded dynamic metering and demand response programs and look to promote them in order to improve resiliency of the grid and potentially reduce the need for peak generation capacity.
• State agencies could work together to develop a more comprehensive framework for integrating renewable energy development into land management and planning.
Education and Communication
• *GEO, the PUC, and utilities could work together to further educate the public about the benefits of tiered pricing and other variable rate structures that could be useful as climate adaptation mechanisms, as suggested by the PUC.*[87]
• *The state should consider doing more to tie climate adaptation and mitigation mechanisms to economic development and job creation opportunities, as suggested by GEO.*[88]

84. GEO interview.
85. PUC interview.
86. Xcel interview.
87. PUC interview.
88. GEO interview.

6 Agriculture Sector in Colorado

Key Points

- The agricultural sector is a complex mixture of different production systems spread across Colorado's varied terrains and different climates, involving thousands of individual producers who operate within the changing context of technology, markets, and policy. The dominant policy forces emanate from federal agricultural regulations and support programs. The state plays a supportive role in marketing, extension, federal policy advocacy, research, and data collection, and through programs such as drought response, water and soil conservation, wildlife interactions, and pest management policy.
- Most agricultural production systems rely to some extent on water resources and thus the sector is sensitive to changes in water supply, policy, management, and infrastructure.
- The sector is further exposed to weather and climate extremes of many types, including extreme heat and cold, winter storms, frost, hail, and flooding, and associated pests and pathogens.
- Despite its exposure to risks, agriculture is widely viewed as particularly adaptable in the face of multiple challenges including climate variability, and the sector in Colorado may be in a position to benefit from some anticipated climate changes, such as warmer conditions and longer growing seasons.

- Barriers to adaptation include market uncertainty at all scales (from local to global), transition costs of changing practices and technology if conditions demand it (including credit and insurance), and increasing competition for water supply.

- Options for facilitating adaptation include mechanisms such as: (1) market development; (2) supportive water policy; (3) drought response; (4) research, extension, and technology transfer; (5) insurance and disaster relief; (6) soil and land conservation policy; and (7) provision of climate information and forecasts.

Overview

Agriculture represents a significant portion of Colorado's economy, with livestock and crop production generating over $6 billion in cash receipts annually and $1.5 billion in net income. The sector is responsible for 23 percent of state exports, with livestock product exports accounting for the largest share of international exports from Colorado. Agriculture is the most extensive land use in the state, with some 37,000 farm and ranch operations. Agriculture is an important water user, accounting for roughly 85 percent of consumptive water use in the state.

Agricultural production is growing in Colorado, with record grain and livestock production and exports in recent years. This is occurring despite land use conversion and competition for water supplies, thus reflecting agriculture's increasingly efficient use of land and water resources.

Colorado agriculture is roughly divided between crop (both irrigated and dryland) and livestock production. Large-scale grain production (especially corn and wheat) dominates the eastern plains, along with irrigated hay and specialty crops, including sugar beets, potatoes, fruit, and vegetables, produced in extensive irrigated swaths supplied by tributaries and mainstems of the South Platte and Arkansas rivers. Groundwater supports irrigation in several plains locations, especially the far eastern plains (including areas drawing on the Ogallala Aquifer), and in the San Luis Valley. Orchard production is concentrated on the West Slope, especially in the Grand, Uncompaghre, and Gunnison valleys, and hay and livestock production dominates agricultural land use in the mountains. Livestock grazing is practiced on rangelands throughout the state, and livestock feeding operations especially concentrate on the eastern plains near sources of irrigated grain production.

Sources of Information for This Chapter

We interviewed representatives of the Colorado Department of Agriculture (CDA), Colorado Water Institute (CWI), CSU's Department of Agricultural and Resource Economics (DARE), and the Rocky Mountain Farmers' Union (RMFU). We also draw on recent climate assessments, while recognizing that no up-to-date regional climate impact assessment is available for the agricultural sector.

Potential Impacts to Colorado Agriculture

Agriculture has long been recognized as one of most climate-sensitive sectors in the United States and globally, and agricultural impacts have figured prominently in climate change assessments for decades.[1] Projected impacts vary considerably across regions depending on climate scenarios, agricultural practices, and assumptions about technology. The first U.S. Nation Climate Assessment examined agricultural effects at the regional scale, including the Rocky Mountain/Great Basin region[2] and the Great Plains,[3] but

1. Easterling, W.E., P.K. Aggarwal, P. Batima, K.M. Brander, L. Erda, S.M. Howden, A. Kirilenko, J. Morton, J.-F. Soussana, J. Schmidhuber and F.N. Tubiello, 2007: Food, fibre and forest products. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, eds., Cambridge University Press, Cambridge, UK, 273-313.
2. Wagner, F.H., ed., 2003: *Rocky Mountain/Great Basin Regional Climate Change Assessment.* Report for the U. S. Global Change Research Program. Utah State University, Logan, UT, USA.
3. Ojima, D.S., and Lackett, J.M., 2002: *Preparing for a changing climate: The potential consequences of climate variability and change–Central Great Plains*, with contributions by the Central Great Plains Steering Committee and Assessment Team: Fort Collins, Colorado State University, 103 pp.

it is now outdated. The more recent Climate Change Science Program (CCSP) Synthesis and Assessment Product 4.3 did review potential impacts on crops, pasture, forage, and animal management,[4] but did not examine regional impacts in detail. Analysts in the western and southwestern states tend to assume that global warming will bring warmer temperatures, and potentially drier conditions, and perhaps worsen some extremes (e.g., droughts) while lessening others (e.g., extreme cold). Recent assessments of potential climate change on water resources in the West and Colorado have also tended to focus on warmer and drier outcomes that place stress on water supplies,[5] and, by implication, on agriculture, especially irrigated farming. Warmer conditions could stress not only surface water supplies but increase demand for groundwater, which in some areas of Colorado is limited by its interplay with surface water (and thus, with surface water allocations) and by fixed volumes of aquifers such as the Ogallala.[6]

Table 6-1

Climate impacts on Colorado's agricultural sector. (Impacts listed in *italics* were addressed by interviewees.)
• Climate variability, expressed especially through fluctuations in soil moisture and water supply, directly affects agricultural production. Agriculture is also particularly exposed to climate extremes, like drought, flood, and extreme heat and cold.
• *Reductions in water supply from changes in precipitation and snowpack are expected to increase competition for water among various industries, including the agriculture sector.*
• Climate warming might encourage the spread of invasive weeds, pathogens and other agricultural pests.
• *Climate warming might increase growing season lengths and associated production, and could increase options for alternative agricultural production.*
• *Climate warming might increase forage availability on Colorado's rangelands by increasing growing season length, but drier conditions could reduce forage available for livestock and wildlife.*
• *Warming conditions could decrease cold stress, but increase heat stress, on livestock.*

Still, we lack a recent, regionally-focused impact study to cast light on potential effects on Colorado's various agricultural production systems. Obviously, different types of agricultural enterprises express different sensitivities to climate variability and change. The climate impacts literature tends to focus on crop production, with dryland (rain-fed) cropping identified as the most sensitive to climate variability, especially to rainfall.[7] Irrigated cropping, including orchards, is sensitive to water resource effects of climate, as well as growing season length, and the potential for longer growing seasons (especially in higher latitudes and higher elevations) noted in many impact studies would certainly influence Colorado agriculture.

Colorado's wide range of agricultural systems also exhibit differing sensitivities to climate variability. Dryland agriculture (predominantly wheat) is sensitive to seasonal precipitation as it affects soil moisture, over-winter moisture and temperature (for winter wheat), and growing season temperature as it affects evapotranspiration in the fields. Irrigated agriculture (a wide variety, but dominated by corn and other livestock feeds) is sensitive to runoff (and thus in most areas also snowpack), as well as growing season temperatures that affect plant water needs.

Livestock production is sensitive to climate effects on grazing lands, climate conditions for livestock health, and the supply of feed crops.

4. CCSP, 2008: *The effects of climate change on agriculture, land resources, water resources, and biodiversity*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Backlund, P., A. Janetos, D. Schimel, J. Hatfield, K. Boote, P. Fay, L. Hahn, C. Izaurralde, B.A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson, D. Wolfe, M. Ryan, S. Archer, R. Birdsey, C. Dahm, L. Heath, J. Hicke, D. Hollinger, T. Huxman, G. Okin, R. Oren, J. Randerson, W. Schlesinger, D. Lettenmaier, D. Major, L. Poff, S. Running, L. Hansen, D. Inouye, B.P. Kelly, L Meyerson, B. Peterson, R. Shaw. U.S. Environmental Protection Agency, Washington, DC., USA, 362 pp.
5. Ray, A.J., J.J. Barsugli, K.B. Averyt, 2008: *Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation*. A report by the Western Water Assessment for the Colorado Water Conservation Board. [Available online at cwcb.state.co.us/public-information/publications/Documents/ReportsStudies/ClimateChangeReportFull.pdf, accessed December 1, 2010.]
6. DARE interview.
7. Easterling et al., 2007.

Climate assessments tend to stress crop production and food supply, while less attention has been paid to livestock production and grazing. The CCSP SAP 4.3 agriculture chapter[8] reviews both range and livestock impacts, but concludes that large knowledge gaps make it difficult to predict the interactive effects of climate change, land management, and domestic and wild animal responses on rangelands. The key effect in Colorado, reflected in the CCSP 4.3 would be on forage production and rangeland health. Our interviews with CDA, WRI and DARE all pointed out that changes in rangelands would affect grazing allocations on the public lands, including federal and state grazing leases. In terms of direct effects on livestock, the CCSP assessment and our interviews suggest that warmer conditions stress livestock in summer and may relieve some stress in winter; indeed, our interviews suggest that the Colorado livestock industry might generally benefit from warmer winters.

Orchards and vineyards are sensitive to irrigation water availability plus seasonal and diurnal temperature thresholds (particularly the risk of frost and freeze in spring). Agriculture is also sensitive to climate impacts on pests, weeds, and pathogens. While the overall effect of climate change on agriculturally-relevant weeds and pests is poorly assessed, concerns have been raised that warmer climates favor invasive weeds, and, on rangeland, woody encroachment.[9]

Finally, Colorado agriculture may be in a good position to benefit from certain climate changes (e.g., warmer temperatures and longer growing seasons). Some of our interviewees noted that longer growing seasons may allow for more diverse crops, while cold weather impacts on the livestock industry would be reduced. Mountain forage production might increase in a warmer climate.[10]

Impacts of Climate Mitigation Efforts

The agriculture sector also has a very strong interest in mitigation (i.e., greenhouse gas reductions), especially through carbon sequestration in soils, and with regard to alternative energy, especially bio-mass and wind power. It is unclear at this time how alternative energy development might affect agriculture's vulnerability and adaptability to climate variability and change. Our interviews with CDA and RMFU especially noted the potential for added income to farmers and ranchers from alternative energy sources. However, the land use, cropping, and policy implications of mitigation, and agriculture's larger role in mitigation, await several developments, particularly federal climate change and/or alternative-energy legislation and further development of alternative energy and carbon markets. We do not further address mitigation in this section.

Adaptation in Agriculture

Adaptive capacity, "the ability or potential of a system to respond successfully to climate variability and change, [including] adjustments in both behavior and in resources and technologies," has been shown to be a necessary condition for effective adaptation strategies.[11] Agriculturalists in Colorado express feelings of both vulnerability and adaptability in the face of global warming.[12] But generally, agriculture is viewed as innovative and adaptable in the face of fluctuations in markets, technologies, and environment. Agricultural production is chiefly market driven, and producers respond directly to market signals, and will do so if the markets begin to reflect climate change impacts (regionally or globally).[13] Given that Colorado's farmers and ranchers operate within national and international markets, impacts and adaptations here depend partly on impacts and adaptations within the sector elsewhere.

8. Hatfield, J., K. Boote, P. Fay, L. Hahn, C. Izaurralde, B.A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson, and D. Wolfe, 2008: Agriculture. *The effects of climate change on agriculture, land resources, water resources, and biodiversity*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington, DC., USA, 362 pp.
9. Hatfield et al., 2008.
10. CWI and DARE interviews.
11. Adger, W.N., S. Agrawala, M.M.Q. Mirza, C. Cone, K. O'Brien, J. Pulhin, R. Pulwarty, B. Smit and K. Takahashi, 2007: Assessment of adaptation practices, options, constraints and capacity. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, eds., Cambridge University Press, Cambridge, UK, 717-743, p. 727.
12. Report of the "listening sessions" of the federal interagency task force on adaptation, Denver, CO. [Available online at www.usda.gov/oce/climate_change/files/PublicMeeting070910.htm.]
13. CDA interview.

Colorado agriculture has already adapted to severe climate challenges in this semi-arid, high elevation, mid-continent climate, including episodic droughts, blizzards, cold snaps, and hail (including the highest frequency of hailstorms in the nation). Additionally, both crop hybrids and livestock breeds are already adapted to suit specific environments. These adaptations were cited in all our interviews [CDA, CWI, DARE, and RMFU] as imbuing a mixture of robustness and resilience into Colorado agriculture that, in a sense, pre-adapts it to climate change. For example, the CDA noted that summer fallow and low-till/high-residue practices now widespread in dryland cropping not only conserve moisture and reduce soil erosion, but also provide a buffer to both drought and heavy precipitation. Seasonal and elevational shifts in livestock grazing, a feature of pastoral systems for centuries, provide flexibility to deal with climate variability. Senior water rights, storage, extensive and inter-connected canal and ditch systems, and water-efficient irrigation practices all reduce the risk of climate-induced losses in irrigated cropping. Finally, social supports such as insurance, disaster assistance, research, and extension round out the roster of adaptive mechanisms.

Federal agricultural policy might enhance or reduce adaptive capacity. Our interviewees especially cited the key role played by provisions of the federal "farm bill" (renewed every five years) in making agriculture more or less adaptable. The state also has a large interest in federal drought policy and federal provision of drought planning and information, for example, through the National Integrated Drought Information System (NIDIS).[14]

Barriers to Adaptation

Our interviewees, and the broader climate impacts literature, recognize some limits on and barriers to adaptive capacity. Despite agriculture's innovativeness and adaptability, a few key concerns showed up in our interviews with regard to climate change:

- Water and agriculture are inextricably linked such that impacts and adaptations in one sector affect the other and water resources are seen as a key area of climate vulnerability in agriculture. The main adaptation need cited to help agriculture deal with climate variability and change is water storage, supported by infrastructure maintenance, modernization, and inter-connectivity.

- Events like the 2002 drought and 2006-07 blizzard and deep snows in southeastern Colorado, demonstrate that agriculture is particularly exposed to risks from extreme climate events that overwhelm normal adaptations and coping mechanisms. If climate change alters the frequency and/or magnitude of extremes, then insurance and disaster relief programs (e.g., USDA disaster designations) could become even more critical, and might be stressed, and the state should be aware of trends in legislation and regulations that could make these programs more or less effective in the future.

- The many unknowns about climate change add greater uncertainty to an industry already facing uncertain markets and the thin profit margins associated with primary production. A big unknown is how climate change will affect other producing areas and national and global markets. The RMFU especially made a point of market vulnerability as part of climate vulnerability, and noted that relatively high debt loads in modern agriculture might detract from adaptive capacity by reducing the resources that farmers and ranchers can deploy to switch crops, buy new equipment, acquire more reliable water supplies, or otherwise respond to a changing environment.

14. See www.drought.gov/portal/server.pt/community/drought.gov/202

Facilitating Agricultural Adaptation

The mission of the CDA is to support a robust agricultural sector, especially through market development as well as programs for outreach, research, local products certification, food safety, weights and measures, and pesticide registration. CDA administers the conservation districts, which play a key role in local response to invasive weeds, erosion, and water conservation. CDA also advocates for agriculture in water resource planning, development and management (as an ex officio member of the CWCB). CDA represents the state's interests to federal agricultural programs.

Outside of water rights administration, the state does not have a strong regulatory role in agricultural production. But the CDA and its Agricultural Commission, other state agencies, the universities, federal government, and producers, processors, and suppliers, collaborate in programs that could affect Colorado agriculture's adaptability in the face of climate change:

- Water and soil conservation
- Drought response, and other hazard and disaster response
- Insurance
- Marketing, market assistance, and trade development
- Wildlife interactions with agriculture
- Weeds, diseases, and other pests
- Research
- Extension
- Data collection

All of these are elements of a modern agricultural system that would be called on to adapt in the face of significant climate change.

The CDA cooperates with the Division of Water Resources and the Colorado Water Conservation Board on water issues related to agriculture. Elements identified as critical to agricultural adaptation to climate variability and change include storage, infrastructural integrity, well permitting, and drought response and drought forecasts.

The CDA, CWCB, and other agencies cooperate via the Drought Mitigation and Response Planning Committee in preparing, updating, and implementing the state drought hazard mitigation and response plan.[15] The drought plan's 2010 update included specific attention to the potential for climate change, concluding that droughts are likely to be more frequent and more intense over the next century.[16]

The governor and the CDA initiate, document, and track requests for federal disaster aid. The vast majority of agricultural disasters are weather and climate related, and federal agricultural disaster assistance can reduce such impacts. This system would logically play a role in response if climate change altered the frequency and/or magnitude of weather and climate extremes.

Agricultural insurance is an important adaptation to weather and climate variability and will be a key mechanism for adaptation to climate change.[17] The CDA has no regulatory role in insurance, and most agricultural insurance used by Colorado farmers and ranchers is funneled through the USDA

15. Colorado Water Conservation Board, 2010: Colorado Drought Mitigation and Response Plan. Colorado Department of Natural Resources, Denver.
16. Colorado Drought Mitigation and Response Plan, Annex C, 23-24.
17. National Research Council, 2010: America's Climate Choices: Adaptation Panel. Washington, DC.

Risk Management Agency (though purely private insurance is also available). CDA raised concerns that inflexible insurance programs that are slow to accommodate new crops and techniques as actuarial data accumulate might act as a brake on adaptation to climate change. Likewise, RMFU raised concerns that agricultural credit is important to allow farmers and ranchers the options to adopt new methods and technologies.

The state plays a key role in agricultural research and education, especially through the CSU system, in cooperation with federal agricultural research programs (e.g., the experiment stations), and the Extension Service. The Extension Service could play an important role in enabling adaptation by providing information and advice in a changing climate.

A key example of research in support of climate impacts assessment and adaptation is the CDA's effort, in cooperation with DARE and others, to develop an integrated simulation model of Colorado agriculture. The model would allow exploration of alternative futures, including scenarios of changes in climate, markets, and technology.[18] In a sense, this is "meta-adaptation," potentially providing insights on impacts and allowing the testing of various adaptations. This is a very valuable approach at this juncture when the future climate is uncertain, and science does not yet provide firm planning targets. The model, when completed, could be used to test different future scenarios, including not just climate change, but other key factors, especially water resources competition, and national and global agricultural markets.

The CDA, in cooperation with the National Agricultural Statistics Service, and the Natural Resources Conservation Service (NRCS; formerly the Soil Conservation Service), collects data on agriculture that would be necessary to identify and quantify the impacts of climate variability and change.

Options: Facilitating Agricultural Adaptation

The agricultural sector in Colorado, already accustomed to coping with weather and climate variability, and uncertain future markets, appears to have tremendous capacity to adapt to climate variability and change. However, this sector also faces challenges from changes in a key production input, water resources, and a key risk, extreme events. Moreover, the sector faces large uncertainties in how climate change will affect agricultural production and markets elsewhere. Finally, the sector faces uncertain future policy; for example, potential changes in crop support programs, and in critical conservation provisions of federal law such as the Conservation Reserve Program. Our review of impacts and the interviews conducted for this sector yield the following options for state adaptation efforts that take advantage of existing adaptive capacity and facilitate existing efforts to make the state's agriculture sector more resilient in the face of future climate impacts.

18. Davies, S., J. Pritchett, A. Davies, E. Fathelrahman, 2009: Examining the Economics of Water Issues in Colorado: An Equilibrium Displacement Mathematical Programming Model. CWI, CSU [This report is the first description and application, to water in this case, of the simulation model of Colorado agriculture].

Table 6-2

Options for state adaptation planning in the agriculture sector
Research, Education, and Communication
• Strengthen support for an effective agricultural research and outreach program as one of the most logical investments in adaptive capacity in the face of an uncertain climate future.
• Conduct a vulnerability assessment to determine whether current adaptive capacity in the agriculture sector is capable of meeting future climate challenges along with the impacts of climate mitigation efforts.
• Further develop tools that allow the state to monitor, simulate, and project the effects of climate variability and change on agriculture in the context of other changes, such as competition for land and water, and federal policy changes.
• Agriculture is a market-driven sector, and it is important for Colorado to assess potential climate-driven changes in national and international agricultural markets.
Planning and Policy
• State officials should carefully consider the cross-cutting impacts of climate on both water and energy sectors, and how they affect agriculture.
• Colorado agriculture has a large interest in federal agricultural policy, changes in which might increase or decrease adaptive capacity. It is important to seek provisions of the next "farm bill" that engender a climate-resilient agriculture, and that reflect the realities of Western agriculture in key policies such as price supports, conservation and research provisions, and other crop and livestock programs.
• Given the possibility that climate change could alter the frequency and/or magnitude of extremes, the state should carefully track federal legislation and regulation trends, as well as business practices, that could make insurance and disaster relief programs (especially USDA disaster designations) more, or less, effective in the future. The state also has a large interest in federal drought policy and federal provision of drought planning and information through, for example, the National Integrated Drought Information System (NIDIS).
• Climate change could affect the allocation of forage to livestock on federal (BLM and USFS) allotments, and the state has a large interest in how this might play out in terms of animal unit months (AUMs) in a changing climate, and the balance of livestock and wildlife use of available forage.

7 Outdoor Recreation Sector in Colorado

Key Points

- The outdoor recreation sector includes a diverse set of government agencies and private actors, although no state agency has overarching regulatory authority over the sector. Colorado State Parks manages state-owned recreational resources and has taken the lead on statewide comprehensive outdoor recreation planning. The Division of Wildlife (DOW) manages hunting, fishing, and wildlife viewing in the state. The Colorado Tourism Office promotes Colorado as a tourism destination. The Colorado Water Conservation Board (CWCB) manages instream flows and recreational in-channel diversions, and has studied interactions between water resources and outdoor recreation.

- Climate variability impacts to outdoor recreation identified by interviewees include drought, insect infestations, wildfire, and harm to aquatic species from warmer water temperatures. These impacts could intensify with climate change. Additional climate change impacts of concern include declining snowpack and its effect on water-based recreation, and increased warm weather visitation to the state.

- Most state agencies with a role in outdoor recreation (CWCB, State Parks, DOW) have started incorporating climate change considerations into planning. Certain industries within the outdoor recreation sector, including the ski industry, have adapted to current climate variability to a significant extent.

- Among the most significant barriers to adaptation are lack of data regarding the impacts of climate on recreation, the need to attend to more immediate concerns, lack of coordination across substantive areas, and lack of stakeholder demand to address climate change adaptation in agency strategic planning.

- Some of the options for this sector include (1) compiling and analyzing data on the economic impact of climate on recreation, (2) addressing the impact of increased outdoor recreation/tourism on transportation, and (3) coordinating outdoor recreation adaptation across industries and levels of government.

Chapter Overview

Colorado offers year-round outdoor recreational opportunities that are integral to its quality of life and a major component of its economic base.[1] We examine climate change adaptation within this sector because locations across the state whose economies are highly dependent on outdoor recreation may experience the greatest effects from a changing climate, whether positive or negative.[2] This chapter provides a brief overview of climate-sensitive tourism and outdoor recreation in Colorado (hereafter referred to as "outdoor recreation") and discusses existing and potential climate impacts, current and planned adaptation efforts, adaptive capacity, and barriers to adaptation, then concludes with a list of options for climate adaptation planning in this sector.

Sources Used to Prepare Report

The research team conducted several interviews for the outdoor recreation sector, some of which overlapped with the Wildlife, Ecosystems, and Forests sector interviews (see chapter 4). At the state level we interviewed representatives of the Colorado Division of Parks and Outdoor Recreation (State Parks) within the State Department of Natural Resources (DNR), and the Colorado Division of Wildlife (DOW) within DNR, but were unable to engage with a representative of the Governor's Office of Economic Development and International Trade (OEDIT) to discuss the potential impacts of climate change on tourism in Colorado. We also spoke with representatives from the USFS White River National Forest and Rocky Mountain Climate Organization, as well as communicated by email with a river outfitter. We did not speak with other public land management agencies that play a role in outdoor recreation such as the National Park Service and Bureau of Land Management, or with industry associations and NGOs.

As in other chapters, we consulted the U.S. Global Change Research Program's 2009 *Global Climate Change Impacts in the United States* report along with the Intergovernmental Panel on Climate Change's Fourth Assessment Report and *Climate Change in Colorado* for information about impacts to this sector. Our discussion of adaptation planning also relied on several state plans and reports that are described below.

Overview of Outdoor Recreation in Colorado

Colorado's outdoor recreation sector provides many activities for residents and visitors that take advantage of the state's climate, scenery, topography, and wildlife. Among these activities are golfing, hiking, camping, wildlife viewing, biking, hunting, four-wheeling, fishing, rafting, kayaking, sailing, climbing, mountaineering, skiing, snowshoeing, and snowmobiling. Twenty-six ski resorts, most of which are located on U.S. Forest Service land, provide downhill skiing and other snow sport activities. Colorado is the number one state in shares of overnight skier visits.[3] National parks and monuments within Colorado provide hiking, camping and other opportunities for approximately 5.5 million visitors per year.[4] State Parks offers boating at 25 water-based parks, including 13 marinas serving the nearly 97,000 boats registered within the state in 2009.[5] Over 11,000 miles of hiking trails can be found throughout the state with 359 miles of trails in Rocky Mountain National Park alone.[6] State Parks manages over 4,000

1. Colorado Economic Development Databook, 2010-2011 edition, p. 1. [Available online at www.colorado.gov/cs/Satellite/OEDIT/OEDIT/1178305420531.]
2. See *Preparing for a Changing Climate: Potential Consequences of Climate Variability and Change*, 2003. A Report of the Rocky Mountain/Great Basin Regional Assessment Team for the U.S. Global Change Research Program. Wagner, F.H., ed. Utah State University, p. 131.
3. Colorado Economic Development Databook, 2010-2011 edition.
4. Colorado Economic Development Databook, 2010-2011 edition.
5. Colorado State Parks Annual Report, 2008-2009.
6. Colorado Economic Development Databook, 2010-2011 edition; see also www.stateparks.com/rocky_mountain.html, accessed November 1, 2010.

campsites across the state,[7] and there are numerous other campsites in national forests and national parks or on private land. Over 500,000 hikers attempt to climb Colorado's 54 mountain peaks over 14,000 feet ("Fourteeners") every year.[8]

Colorado's overall travel and tourism industry generated over $13.6 billion in 2009. Of this total, $9.73 billion was from domestic overnight visitors. The remainder was from international visitors and day trips.[9] Annual statewide economic benefits from outdoor recreation over the past few years have been estimated as anywhere from $8.5 billion to $15 billion, depending on which activities are included and the methodologies used.[10] Recent estimates of participation in and economic impacts of some of the most popular outdoor activities are shown below:

Table 7-1

Outdoor Activity Participation and Economic Impact			
	Participants	**Economic Impact**	**Timeframe**
Downhill Skiing[11]	11.85 million	$2.6 billion	2009-10
Rafting[12]	486,151	$142 million	2009
Colorado State Parks[13]	12 million	$571 million	2008-09
Hunting, fishing[14]	12.7 million	$1.8 billion	2007
Wildlife viewing[15]	9.4 million	$1.2 billion	2006

Although private lands offer some opportunities, the bulk of outdoor recreational activities take place on public lands managed by federal and state agencies. Approximately 35 percent of Colorado's 66.5 million acres of land are owned by the federal government[16] and another 5 percent by state government.[17] While no single state agency has overarching regulatory authority over the outdoor recreation sector in Colorado, the following state agencies (described below in Table 7.2) have management or other roles within this sector:

- State Parks within the Department of Natural Resources (DNR)
- Colorado Water Conservation Board (CWCB) within DNR
- Colorado Division of Wildlife (DOW) within DNR
- Colorado Tourism Office (CTO) within the Governor's Office of Economic Development and International Trade (OEDIT)[18]

7. www.parks.state.co.us/camping/Pages/camping.aspx, accessed November 1, 2010.
8. Colorado Fourteeners Initiative website. [Available online at www.14ers.org/resources_notrace.php, accessed November 29, 2010.]
9. Colorado Economic Development Databook, 2010-2011 edition.
10. Colorado Water Conservation Board, 2010: *Colorado Drought Mitigation and Response Plan, Annex B: Recreation Sector*. [Available online at cwcb.state.co.us/water-management/drought/Documents/StateDroughtMitPlan2010/Annex%20BChapter10RecreationSector.pdf, accessed November 10, 2010]; Colorado State Parks, 2008: *Colorado Statewide Comprehensive Outdoor Recreation Plan (SCORP)*. [Available online at www.parks.state.co.us/Trails/LWCF/SCORPPlan/Pages/SCORPplan.aspx, accessed November 15, 2010.]
11. Colorado Ski Country USA Facts and Stats. [Available online at www.media-coloradoski.com/CSCFacts/, accessed November 1, 2010.]
12. Colorado River Outfitters Association, 2009: *Commercial River Use in the State of Colorado 1988 – 2009*.
13. *Colorado State Parks Annual Report, 2008-2009*. Visitors to the State Parks engaged in boating, camping and hiking, among other outdoor activities. Economic impact is the estimated direct spending within 50 miles of a state park by both local and non-local visitors.
14. BBC Research and Consulting, 2008: *The Economic Impacts of Hunting, Fishing and Wildlife Watching in Colorado.* Number of "visitors" is expressed in terms of "hunting and fishing activity days" which refers to one hunter or angler spending at least part of one day hunting or fishing. Economic impacts are both direct and secondary.
15. Id. at 13. Participants expressed in terms of activity days.
16. CRS, 2004: *Federal Land Management Agencies: Background on Land and Resources Management.* Congressional Research Service Report to Congress, updated August 2, 2004.
17. See chapter 4.
18. OEDIT "offers a host of programs and services tailored to support business development at every level." [Available online at www.colorado.gov/cs/Satellite/OEDIT/OEDIT/1167928099897, accessed November 26, 2010.]

Table 7-2: State Agencies with an Outdoor Recreation Role

Agency	Decision making authority	Planning with a recreation component	Recreation responsibilities
State Parks	Policy set by five-member Colorado State Parks Board	Lead author for the 2008 Statewide Comprehensive Outdoor Recreation Plan (SCORP) Strategic plan, updated 2010	• Manages over 225,000 acres of land and water at 42 state parks • Administers the registration program for the nearly 97,000 boats within the state • Manages a statewide network of trails to provide recreation, link open space, and provide access to public lands • Administers Land and Water Conservation Fund state matching grants in the state of Colorado • Oversees the Colorado Natural Areas Program, a statewide program focused on the recognition and protection of areas that contain at least one unique or high-quality natural feature of statewide significance[19] • Oversees the statewide snowmobile and off-highway vehicle (OHV) programs, which register over 33,000 snowmobiles and 133,000 OHVs each year, respectively • Regulates licensed river outfitters and administers annual licensing program[20]
DOW	Policy and regulations set by 11-member Colorado Wildlife Commission	Colorado Division of Wildlife Strategic Plan 2010-2020	• Administers hunting and fishing licenses • Manages the state's game species • Responsible for more than 230 wildlife areas available for public recreation
CTO	Governed by a 15-member board of directors[21]		• Promotes Colorado as a tourism destination • Commissions an annual study to identify the impact of tourism on the state's economy[22]
CWCB	Policy set by 15-member Colorado Water Conservation Board	2004 and 2007 Statewide Water Supply Initiative (SWSI) Phase 1 and 2 reports 2010 State Drought Mitigation and Response Plan annex B	• Responsible for appropriation, acquisition, protection and monitoring of instream flow and natural lake level water rights[23] • Reviews all applications for recreational in-channel diversions[24]

Great Outdoors Colorado (GOCO) also plays a role in the sector by providing funding to Colorado's wildlife, parks, rivers, trails, and open spaces from state lottery proceeds.

The U.S. Forest Service (USFS), within the U.S. Department of Agriculture, is the largest single federal land management agency in the state with 14.5 million acres. The USFS issues permits for skiing on US forest lands with terms and conditions.[25] Twelve of the state's 26 downhill ski resorts are located

19. There are 79 designated natural areas which comprise 141,033 acres in addition to the state parks.
20. *Colorado State Parks Annual Report, 2008-2009*; Colorado State Parks website. [Available online at www.parks.state.co.us/About/Pages/AboutUsDefault.aspx, accessed November 12, 2010.]
21. Colorado Tourism Office. [Available online at www.colorado.com/industrypartners/ColoradoTourismOffice.aspx, accessed November 5, 2010.]
22. CTO Overview and FAQs. [Available online at www.colorado.com/IndustryPartners/ctooverviewandfaq.aspx, accessed November 5, 2010.]
23. CWCB Instream Flow Program website. [Available online at www.cwcb.state.co.us/environment/instream-flow-program/Pages/main.aspx, accessed November 12, 2010.]
24. CWCB Recreational In-Channel Diversion website. [Available online at www.cwcb.state.co.us/environment/recreational-in-channel-diversions/Pages/main.aspx, accessed December 8, 2010.]
25. 16 U.S.C. § 497b, National Forest Ski Area Permit Act of 1986.

within the US Forest System's White River National Forest in Colorado. Other relevant federal agencies include the Bureau of Land Management which oversees 8.4 million acres, the National Park Service with approximately 650,000 acres, the US Fish and Wildlife Service (USFWS) that manages about 85,000 acres within the National Wildlife Refuges in Colorado,[26] and the Bureau of Reclamation that owns several reservoirs with fishing, boating and camping opportunities. These agencies and their climate planning efforts are described in chapters 3 and 4.

In addition to these state and federal agencies, thousands of private companies, individuals, and non-profit organizations are part of Colorado's outdoor recreation industry. Examples include the Colorado Mountain Club, Colorado Ski Country USA, International Mountain Biking Association, Access Fund, Outward Bound, Trout Unlimited, Ducks Unlimited, Great Outdoors Colorado, Bicycle Colorado, and Colorado Off-Highway Vehicle Coalition.

Climate Impacts on Colorado Outdoor Recreation

Table 7-3 summarizes findings about potential climate change impacts to the outdoor recreation sector.

Table 7-3

Projected Climate Change Impacts Applicable to Outdoor Recreation in Colorado[27] (Impacts listed in italics were addressed by the interviewees.)
• A changing climate will mean reduced opportunities for some activities and locations, and expanded opportunities for others.
• *Some regions will see an expansion of the warm weather recreation season.* The net economic impact of near-term climate change on outdoor recreation is likely to be positive. Long-term impacts are much more uncertain.
• Rising temperatures could cause ecosystem degradation that would affect the quality of recreation experiences for hikers, bikers, birders and others
• *Climate-induced changes in the frequency of fire or insect outbreaks across western North America* will also affect national park visitation, although the magnitude of those impacts are uncertain.
• *The high-elevation snowpack in the Colorado River Basin is projected to experience a moderate decline.*
• At high elevations mid-winter temperatures would remain below freezing even with relatively large warming, and the main effects of rising temperatures on snowpack would occur in the spring.
• Earlier wet snow avalanches could force ski areas to shut down affected runs before the season ends.
• 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.
• Hunting and fishing will change as animal habitats shift and relationships among species in natural communities are disrupted by different responses to climate change.
• *Cold-water fisheries are expected to be negatively affected by climate change and cold-water species may disappear from all but the deeper lakes*.

26. *Federal Land Management Agencies: Background on Land and Resources Management.*
27. Sources: Karl, T. R., J. M. Melillo, and T. C. Peterson, eds., 2009: *Global Climate Change Impacts in the United States.* Cambridge University Press; Field, C.B., L.D. Mortsch, M. Brklacich, D.L. Forbes, P. Kovavs, J.A. Pastz, S.W. Running and M.J. Scott, 2007: *North America: Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, eds., Cambridge University Press, Cambridge, UK, 617-652; Ray, A.J.. J.J. Barsugli and K.B. Averyt, 2008: *Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation*. A report by the Western Water Assessment for the Colorado Water Conservation Board.

Participants at a 2007 Climate and Tourism on the Colorado Plateau workshop observed that snow and water-based recreation in the region already experiences lower revenue in years of below-average snowpack as well as increased operational costs for snowmaking at ski areas. The workshop report noted that "projected impacts tied to rising temperatures threaten long-term profit margins of many tourism industries on the Colorado Plateau."[28]

State Parks interviewees described current climate variability impacts to outdoor recreation, all of which may intensify with climate change. State Parks saw a visitation decline during 2002, most of which was believed to be drought-related.[29] Water-based state parks—which are the large revenue-generating parks within the system[30]—were especially hard hit by the 2002 drought. Boat ramps in the state parks were unusable due to low water levels, and several lakes and reservoirs were forced to close early.[31] State Parks interviewees noted that motor boat registrations dropped during the drought as fewer boat ramps reached the water.[32]

Increased risk of wildfire, a secondary impact of drought, was another concern raised by State Parks representatives. Wildfire risk can lead to fire bans, and state parks see significant reductions in visitation during fire bans because people do not want to camp in the parks when campfires are prohibited. Reduced campground visitation is a concern because State Parks' operating budget is increasingly dependent on park passes and camping fees rather than the state's general fund.[33]

Interview subjects also discussed potential tourism impacts from the death of millions of acres of Colorado's forests caused by the mountain pine beetle (MPB). The hazard posed by falling trees killed by the MPB forced the closure of three State Parks campgrounds in the past year, resulting in the temporary loss of camping fee revenues as well as a "much different experience" for campers after trees were removed. The MPB epidemic has also led to closures of trails funded by State Parks and has had a substantial impact on the State Parks budget due to the cost of tree removal as well as revenue losses.[34] National forests across Colorado have also closed trails and campgrounds due to the MPB epidemic.

Interviewees mentioned impacts to aquatic species from warmer water temperatures.[35] The State Parks interviewees are concerned that rising stream temperatures are reducing desirable habitat for native cutthroat trout.[36] Aquatic species are particularly vulnerable to drought and critical species had to be rescued during the 2002 drought.[37]

Impacts to land-based animals from current climate variability are less clear. The 2010 drought plan's vulnerability assessment found that, in general, the 2002 drought had limited impacts on big game populations but did have consequences for bird production.[38]

Members of Colorado's outdoor recreation industry maintain that negative public perception about wildfire resulting from public statements has hurt their businesses more than the events themselves. River outfitters interviewed for the 2010 *Colorado Drought Mitigation and Response Plan*, for example, attributed the significant decline in rafting customers in 2002 to negative public perception about wildfire more than low streamflows.[39]

28. Alvord, C., P. Long, R. Pulwarty and B. Udall, 2008: *Climate and Tourism on the Colorado Plateau*. Meeting Summaries. Bulletin of the American Meteorological Society, May, 673-675.
29. Luecke, D. F., J. Morris, L. Rozaklis, and R. Weaver, 2003: What the Current Drought Means for the Future of Water Management in Colorado. [Available online at www.westernresourceadvocates.org/media/pdf/Drought_Report.pdf, accessed January 4, 2011]; see also *Colorado Drought Mitigation and Response Plan*.
30. State Parks interview.
31. Luecke et al., 2003; see also *Colorado Drought Mitigation and Response Plan*.
32. State Parks interview.
33. State Parks interview. The percentage of State Parks' operating budget from the general fund has declined from about 25% in FY 2000-01 to about 6% in FY 2009-10, and will decline to 0% in FY 2011-12. Colorado State Parks 2010 Strategic Plan.
34. State Parks interview.
35. See chapter 4 for a fuller discussion of this issue.
36. State Parks interview.
37. *Colorado Drought Mitigation and Response Plan*.
38. *Colorado Drought Mitigation and Response Plan*.
39. *Colorado Drought Mitigation and Response Plan*.

One major area of concern about the impacts of climate change on outdoor recreation is declining snowpack and its effect on water-based recreation.[40] The city of Aspen, Colorado, was concerned enough about the impact of climate change on local skiing to commission a study of modeled impacts to skiing under different emissions scenarios in the years 2030 and 2100. *Climate Change and Aspen: An Assessment of Impacts and Potential Responses* found the following impacts to skiing in Aspen:

- The ski season will start later and end earlier in both 2030 and 2100
- Early season snow depths will be reduced as more precipitation falls as rain instead of snow
- Spring melting will start earlier
- Maximum snowpack will occur early in February under the middle and high emissions scenarios (currently this occurs in March)
- By 2100 there will be no consistent winter snowpack at the ski area base except possibly under the lowest emissions scenario
- Snow quality will likely degrade more in the spring than in the fall
- Under the highest emissions scenario, no skiable snow will exist at the base by 2100
- Despite adaptation options, climate change would become progressively more problematic to the ski industry as the century progressed[41]

Climate Change in Colorado reported projections of modest declines in snowpack (10-20 percent) during the winter for areas above 8,200 feet by 2040–2069. The report noted that the extent of springtime snowpack declines will depend on elevation and emissions scenario.[42]

The river outfitter indicated that the rafting industry has not reached consensus on whether climate change will be a significant issue for them. Currently outfitters are more concerned about other factors including the economy, changing marketplace, and buying habits of travelers. They acknowledge, however, that increased drought, smaller snowpacks and a quicker melt cycle will shorten the rafting season, which could challenge the industry's viability.[43] The Aspen study found that significantly reduced flows in June 2100 would reduce the rafting client base of the Upper Roaring Fork River.[44]

State Parks has not yet seen any climate change-related impacts to hunting. As discussed in chapter 4, interviewees expect that warming temperatures will lead to northward and upward shifts in the ranges of animal species which could mean contraction of their ranges and possible extinction. The DOW representative acknowledged that climate change potentially could impact hunting and fishing but the agency wants more research on the topic before it will reach a definite conclusion.[45] The Aspen study found that, under climate change scenarios, lower flows in June and July and increased water temperatures could have adverse effects on trout spawning, stream insect development, and trout survival, thereby impacting fishing.[46]

Rocky Mountain Climate Organization (RMCO) noted that increased warm weather visitation to the state is a potentially large climate change impact. RMCO pointed out that no one is looking at the impact of that increased visitation on state transportation resources.[47]

40. E.g., State Parks interview.
41. *Climate Change and Aspen: An Assessment of Impacts and Potential Responses*, 2006. A Report of the Aspen Global Change Institute prepared for the city of Aspen. Prepared by Aspen Global Change Institute, Center of the American West, The Rural Planning Institute, Stratus Consulting Inc., and Wildlife and Wetland Solutions, LLC.
42. Ray et. al, 2008: pp. 2, 37-38.
43. Email communication with river outfitter.
44. *Climate Change and Aspen*.
45. DOW interview.
46. *Climate Change and Aspen*.
47. RMCO interview.

Current and Planned Adaptation Efforts

In this section we summarize climate variability and climate change adaptation efforts relating to outdoor recreation that have been completed or are underway, planned, or being considered at three state agencies—the Colorado Water Conservation Board, State Parks, and the Division of Wildlife—as well as the National Park Service. References are made to other chapters in this report that include more extensive discussion of these efforts.

Colorado Water Conservation Board programs, plans, and studies are of particular relevance to the outdoor recreation sector because of the importance of water to so many activities (including fishing, boating, rafting, kayaking, and skiing). Although they do not specifically address climate change, several CWCB studies can provide guidance to the outdoor recreation sector as it faces a future of more limited water supplies. The Statewide Water Supply Initiative (SWSI) includes an examination of the water uses and needs of the outdoor recreation sector.[48] Phase 2 of the SWSI project has assembled information about recreation resources, described examples of successful recreation projects and strategies, and identified potential future projects, funding sources and tools. SWSI created Basin Roundtables, discussed in detail in chapter 3, each of which is charged with assessing both environmental and recreational needs.[49]

The CWCB conducted a drought vulnerability assessment for water-dependent outdoor recreation in its 2010 *Drought Mitigation and Response Plan*. The Recreation Sector chapter summarizes drought impacts to skiing, wildlife viewing, hunting/fishing/camping, golfing, boating, and rafting. The State Assets chapter summarizes drought impacts to, among other state assets, State Parks, DOW, and instream flows. Each chapter then discusses the adaptive capacity of the sub-sector or state asset and applies a set of vulnerability metrics developed in the report. The Recreation Sector report makes two overarching recommendations: (1) use public relations to mitigate or prevent negative public perceptions of Colorado recreation during drought, and (2) diversify activities and/or tourist areas, as well as the seasonality of offerings.[50] The State Assets chapter recommends increased drought awareness and planning, awareness of vulnerabilities by state agencies, coordinated media plans, and data gathering.[51]

Planning specifically for climate change adaptation is beginning to emerge within state agencies that have a role in the outdoor recreation sector. State Parks representatives noted that most of the outdoor recreation industry—including the Parks Board—is aware that climate change is a concern. The Parks Board and leadership team "know that what's occurring right now is linked to what's going on with the climate…there's big things happening here, and we've got to address these things that are on our front doorstep now, but we'd better start planning for the future."[52]

State Parks' 2008 Statewide Comprehensive Outdoor Recreation Plan (SCORP) is possibly the first state agency-authored plan in Colorado that explicitly recommends climate change adaptation measures for outdoor recreation. The federal Land and Water Conservation Fund (LWCF) requires that states prepare a SCORP to be eligible for LWCF funding. LWCF funding is used to acquire land or water for recreational purposes; to build or redevelop outdoor recreational facilities; for planning to address needs, problems or issues identified in the SCORP; or to fund production of an upcoming SCORP.[53] The LWCF provides a great deal of flexibility concerning the contents of these plans and does not require

48. *Statewide Water Supply Initiative Report*, November 2004. Prepared for the Colorado Water Conservation Board. [Available online at www.cwcbweblink.state.co.us/WebLink/ElectronicFile.aspx?docid=144066&searchid=2c16c041-d0b2-4ec5-ac42-8b95aa0c04e3&dbid=0, accessed December 8, 2010]; *Colorado's Water Supply Future: Statewide Water Supply Initiative Phase 2*. November 2007. Prepared for the Colorado Water Conservation Board. [Available online at www.cwcb.state.co.us/public-information/publications/Documents/ReportsStudies/TechnicalRoundtableReportFinalDraft.pdf, accessed December 8, 2010.] SWSI is discussed more fully in chapter 3.
49. Nonconsumptive Needs website. [Available online at www.cwcb.state.co.us/environment/non-consumptive-needs/Pages/main.aspx, accessed December 9, 2010.]
50. *Colorado Drought Mitigation and Response Plan, Annex B: Recreation Sector.*
51. CWCB, 2010: *Colorado Drought Mitigation and Response Plan, Annex B: State Assets Sector*. [Available online at www.cwcb.state.co.us/water-management/drought/Documents/StateDroughtMitPlan2010/Annex%20BChapter5StateAssetsSector.pdf, accessed November 10, 2010.]
52. State Parks interview.
53. The Colorado LWCF Program. [Available online at www.parks.state.co.us/Trails/LWCF/LWCFGrants/Pages/LWCF%20Grant%20Information.aspx, accessed November 5, 2010.]

discussion of climate change. The State Parks leadership has considered the SCORP a priority because of the importance of recreation in the state. Stakeholder engagement in the SCORP process is critical; Colorado's 2008 process included a 34-member steering committee with a diverse set of stakeholders. The SCORP Steering Committee identified climate change as one of the most significant issues affecting outdoor recreation in Colorado, particularly with regard to the ski industry, and that input led to inclusion of climate change as one of the highest priority issues in the plan.[54]

The SCORP strategic plan defined two climate change adaptation-related objectives: (1) develop a better understanding of how climate change may impact recreation and tourism in Colorado, and (2) lessen the impact of future climate change on Colorado's recreation and tourism economy, while dealing with some of the impacts that are likely to occur. Within those objectives specific supporting actions included:

- obtaining research that clearly identifies potential impacts of climate change on recreation and tourism, including specific indicators, mitigation strategies, alternatives for existing recreation activities that will be heavily impacted, and surveys of visitor perceptions about climate change and related impacts;
- incorporating climate change adaptation into agency strategic and operational planning which would include modification of design and engineering standards to anticipate more heat, severe weather, droughts and floods;
- working with the ski industry and others to plan for an initial increase and then an eventual decline in skiers including the expansion of summer recreation; and
- protecting and restoring critical fish and wildlife habitat.

The plan also recommended better integration of outdoor recreation into considerations of land use and transportation planning.[55]

State Parks indicates that partial progress has been made toward implementing many of the SCORP climate change adaptation recommendations, Examples cited include the CWCB's Colorado River Water Availability Study, "Greening Government" executive orders regarding matters such as fleet choices and building design standards, and this report.[56]

Climate change is an issue that also factored into the development of State Parks' 2010 Strategic Plan goals and objectives. While State Parks is not currently planning to develop an agency-wide climate adaptation plan, it acknowledges that this may be necessary to take on sooner rather than later. Right now, there are numerous other pressing needs that are demanding more immediate resources and attention. State Parks recognizes that this is an issue despite the fact that it was not brought up by the public or staff (which were only two of the factors that were considered in developing the strategic plan).[57]

State Parks interviewees indicated several ways they are starting to think about integrating consideration of climate change into agency decision making. For example, if water levels at its reservoir parks continue to drop as a result of climate change, State Parks may have to consider "pulling out and trying to focus on other lands that offer a greater or a better outdoor recreation experience,"[58] although this could create significant impacts since a large part of their revenue comes from water parks such as Lake Pueblo. Bonny Reservoir has already been seasonally closed and its staff reduced; full closure is under consideration. State Parks would like to incorporate available data about the impacts of climate change on outdoor recreation into a plan to assess the park system's sustainability. State Parks representatives noted that "We may indeed reduce the size of our system, and impacts from climate would certainly be a factor."[59]

State Parks already incorporated concerns about climate change impacts into the current Roxborough

54. State Parks interview.
55. SCORP.
56. SCORP Implementation Summary. [Available online at www.parks.state.co.us/SiteCollectionImages/parks/Planning/SCORP%20Implementation%20Summary2010.pdf, accessed November 12, 2010.]
57. State Parks interview.
58. State Parks interview.
59. State Parks interview.

Park management plan. The plan notes that "water availability may be a key issue for Roxborough in future years with the increasing pressures of climate change ... Warmer temperatures affect evaporation rates in water bodies and changes in runoff due to earlier spring snowmelt, which may alter Roxborough's hydrology."[60] The interviewees acknowledged that they needed to make a more concerted effort to integrate climate change into management plans which could serve as a type of "mini-climate action plan."[61] They also discussed the possibility of incorporating information about climate change in interpretive programs and media provided at many of the 42 state parks. As a current adaptation response, State Parks reduced the vulnerability of campgrounds and surrounding residential areas to fire by installing hoses and ember grills at some of its newer parks. To meet the concerns of residents near Cheyenne Mountain State Park in El Paso County about campfires, State Parks provided a fire truck to ensure a quick attack response to any fire issue that may arise. While this response is not necessarily related to climate change, it indicates the type of measures that might be needed in the future to insure support of camping at some parks in the wake of a warmer, drier environment. Finally, State Parks employs a water expert who tracks water levels and, when necessary, purchases additional water rights.[62]

Climate adaptation planning activities of the Division of Wildlife, addressed in detail in chapter 4, include discussion of climate change in the 2010–2020 Strategic Plan and plans to complete a climate change update to the State Wildlife Action Plan (SWAP) by 2015.

Adaptation activities of interest at the federal agency level include the National Park Service's Climate Change Response Program, based in Ft. Collins. The program, which recently released the NPS's *Climate Change Response Strategy*, uses scenario planning as a tool for park managers to plan for an uncertain future.[63]

Industry Adaptive Capacity

Adaptation to climate change in Colorado's outdoor recreation industry is likely to result, in part, from private sector decisions building on existing adaptive capacity. The ski industry has learned to adapt to a highly variable climate by employing snowmaking, originally adopted in the late 1970s as a drought coping response.[64] Most Colorado ski resorts now use snowmaking to smooth out early season snow variability and ensure consistent opening dates,[65] and the IPCC and others report that snowmaking could help lower the vulnerability of the ski industry to projected impacts of climate change.[66] Other examples of climate change adaptation strategies for the ski industry include expanding snowmaking in warmer temperatures, expanding snowmaking at higher elevations, making and stockpiling more snow, attaining more water rights and building more water storage, adjusting grooming techniques, adding higher skiing terrain, providing hourly ski reports to allow skiers to take advantage of optimal snow conditions, downloading skiers past melted out areas, and seeding clouds.[67] The Aspen study found that Aspen's mountain managers were "somewhat confident" they could adapt to future snow conditions under a middle emissions scenario by adding snowmaking at the top of the mountain, extending the snowmaking season by a few weeks, and opening a few weeks later.[68]

CWCB's drought plan, the SCORP, the Aspen study, and others note the potential for ski areas to adapt to climate change by diversifying revenue sources through year-round recreation.[69] The Ski Area Recreational Opportunity Enhancement Act was introduced by U.S. Senator Mark Udall of Colorado to amend the National Forest Ski Area Permit Act of 1986 to give the USFS authority to allow recreational uses other than skiing at ski resorts on national forests. The act would enable ski resorts to diversify if skier visits decline due to deteriorating snow conditions.

60. Colorado State Parks, 2010: *Roxborough State Park Management Plan 2010-2020*, September.
61. State Parks interview.
62. State Parks interview.
63. NPS, 2010: *Climate Change Response Strategy. National Park Service,* September, 28 pp.
64. *Colorado Drought Mitigation and Response Plan*.
65. *Preparing for a Changing Climate: Potential Consequences of Climate Variability and Change*, 2003.
66. *Impacts, Adaptation and Vulnerability*, 2007.
67. *Climate Change and Aspen*.
68. *Climate Change and Aspen*.
69. See *Colorado Drought Mitigation and Response Plan; SCORP* ; *Climate Change and Aspen*.

Barriers and Gaps to Adaptation

Several barriers and gaps emerged from the interviews. They can be grouped into the following categories: (1) information gaps, (2) institutional barriers, and (3) conceptual barriers. Options are provided where appropriate.

Information Gaps

Lack of data regarding the impacts of climate on recreation was identified as a significant gap by our interviewees. For example, State Parks would like to know the impact of a half-inch monthly decline in precipitation on outdoor recreation, as well as which parks were especially vulnerable to climate change. The latter type of information could be incorporated into a tool used to help identify parks that should be closed.[70] DOW would like to see additional research on the connection between forests impacted by MPB and hunting and fishing in those areas, as well as how waterfowl hunters are being impacted by changes in bird migration patterns and timing. The DOW interviewee questioned, for example, whether hunters are having less success because migration patterns are changing.[71] The White River National Forest interviewee acknowledged that "we just don't have much information on [the effects of climate on recreation] . . . that we can really depend on or we've spent enough time looking at."[72]

Option: Obtain information about climate change impacts to outdoor recreation. Approach the research arm of the US Forest Service as a potential source for this type of information.[73]

State Parks also identified a broader need for more accurate data quantifying the economic impact of outdoor recreation in the state. Although the CTO's *Longwoods* study of tourism trends[74] quantifies the ski industry's economic impact on the state, it does not separate out the impacts of other forms of outdoor recreation from general tourism trends.[75]

Option: Obtain more accurate estimates of the economic impact of outdoor recreation in the state to provide baseline information for quantifying climate change impacts on the sector.

Institutional Barriers

While State Parks acknowledges that climate change is an issue in its 2010 Strategic Plan, it did not receive pressure from the general public or other state park stakeholders to specifically address climate change adaptation. Greater stakeholder input could raise the importance of climate change adaptation in State Parks' strategic planning process ("the more push we get, the more it helps").[76]

Option: Public education and outreach to stakeholders about the impacts of climate change on outdoor recreation could increase stakeholder support for incorporating adaptation into agency strategic planning.

Most of the outdoor recreation sector interviewees, as well as the SCORP, mentioned the need for greater attention to the interaction between outdoor recreation and transportation.[77] This interaction will become even more critical if climate change increases warm weather visitation to the state, yet no one is currently studying it.[78]

Option: Coordinate outdoor recreation adaptation across governmental agencies and substantive areas.

Barriers to enhanced snowmaking include the need for additional water and water storage.

70. State Parks interview.
71. DOW interview.
72. USFS interview.
73. See USFS interview.
74. See Longwoods International, 2010. Colorado Travel Year 2009. [Available online at www.colorado.com/IndustryPartners/LongwoodsInternational.aspx, accessed November 5, 2010.]
75. State Parks interview.
76. State Parks interview.
77. SCORP; State Parks interview; USFS interview; RMCO interview.
78. RMCO interview.

Snowmaking also raises concerns about environmental impacts such as dewatering streams during low-flow periods and altering the hydrologic cycle. Snowmaking during low flow periods may increase adverse effects on fisheries that also will be affected by low flows from climate change. Environmental opposition could jeopardize the ability of ski areas to obtain future water rights. Finally, snowmaking requires significant amounts of electricity which would drive up ski area costs.[79]

Option: Investigate whether and how the state of Colorado might support industry efforts to adapt to climate change such as enhanced snowmaking.

Conceptual Barriers

Despite awareness of and concern about climate change, a long list of issues including habitat conversion, MPB, drought, wildfire, human population growth, wildlife diseases, and sustainability demand more immediate attention from agencies.[80] The river outfitter also noted that outfitters are more concerned about the economy, changing marketplace, and buying habits of travelers than climate change.

Facilitating Adaptation in Colorado's Outdoor Recreation Sector

The recreation industry is iconic for Colorado. A change in recreation opportunities such as shortening of the snow season or lengthening of the warm season would have important impacts on the state's economy and society.

Because the participants in this sector are diverse, it is difficult to generalize about their perspectives on climate change adaptation. From the limited number of interviews we conducted it appears that members of the sector are aware that climate change is or could be a significant concern. However, despite the obvious climate sensitivities in the sector, little is known in detail about how climate variability affects outcomes in this sector. Like the Colorado Department of Agriculture's development of a tool to assess responses in the agriculture sector and the CWCB's development of a drought vulnerability tool kit, it might make sense to develop more data and analytical capacity focused on recreation, its role in the state's economy, and the impacts of changes in market forces, technology, related sectors, and climate.

Outside of the State Park system and the state's role in prompting Colorado travel and tourism, the sector is only loosely organized. One effort the state might engage in is to encourage collaboration and information sharing across the vast array of recreational interests, from local to national, private to public, and provider to consumer. One option that emerged from our interviews is to use the federal/state/private/local collaboration that has developed to address the mountain pine beetle as a model to coordinate outdoor recreation adaptation throughout the state's recreation sector.

The following table summarizes options for adaptation in the outdoor recreation sector that emerged from our review of the interviews conducted for this sector:

Table 7-4

Options for state adaptation in the outdoor recreation sector
• More accurately quantifying the economic impact of outdoor recreation in the state
• Compiling data on the economic impact of climate on recreation. Data might be gathered by the USFS research station or through the CTO's annual studies of tourism trends
• Creating a clearinghouse of recreation impacts data that can be used in agency planning efforts
• Addressing the impact of increased summer outdoor recreation/tourism (and recreation in general) on transportation
• Providing visitors at State Parks visitor centers and other potential stakeholders with information about climate change
• Using the federal/state collaboration that has been developed to address the MPB as a basis, create an entity that will coordinate outdoor recreation adaptation across industries and government levels

79. *Colorado Drought Mitigation and Response Plan*; *Climate Change and Aspen; Preparing for a Changing Climate*, 2003.
80. State Parks interview; DOW interview

8 Adaptation Planning in Other States

This section focuses on three of the most proactive states in climate change adaptation—Maryland, Alaska, and California—in order to provide a survey of the state-of-the-art in state adaptation planning. We first outline two approaches to adaptation planning. We then examine the actual planning experience in these three states.

Adaptation Planning Approaches

The following are two adaptation planning approaches that provide useful guidance for how the state of Colorado might initiate a state adaptation planning effort.

The state of Alaska's Immediate Action Workgroup (IAWG) provides a "Recipe for Success" in their final report[1] that includes these steps:

- Begin by developing a collaborative organizational structure that can focus the combined capabilities of local, regional, state, and federal stakeholders on the problems at hand.
- Discuss the nature and extent of the potential climate change impacts and create an applied approach to addressing significant impacts, as described in Step 3.
- Identify the communities at risk, timeframe, and the true needs to address climate change impacts. Develop a methodology for prioritization of needs based on the risk to lives, health, infrastructure, homes, businesses, subsistence harvests, significant cultural attributes, and the quality of life. Next, determine the true needs of coastal communities subjected [to] climate change impacts.
- Develop measures that meet the stated needs and combine those measures into alternative plans for comparison.[2]

1. IAWG, 2009: Immediate Action Workgroup, Recommendations to the Governor's Subcabinet on Climate Change.
2. Id.

Similarly, King County, Washington released a guidebook *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments* in 2007[3] to help decision-makers "in a local, regional, or state government prepare for climate change by recommending a detailed, easy-to-understand process for climate change preparedness based on familiar resources and tools." The King County "Suggested Checklist for Governments on How to Prepare for Climate Change" is bulleted below.

- Initiate your climate resiliency effort
  - Scope the climate change impacts to your major sectors
  - Pass a resolution or administrative order directing your government to prepare for climate change
  - Build and maintain support to prepare for climate change
  - Build your climate change preparedness team
  - Identify your planning areas relevant to climate change impacts
- Conduct a climate resiliency study
  - Conduct a climate change vulnerability assessment
  - Conduct a climate change risk assessment
  - Prioritize planning areas for action
- Set preparedness goals and develop your preparedness plan
  - Establish a vision and guiding principles for a climate resilient community
  - Set your preparedness goals
  - Develop, select, and prioritize your preparedness actions
- Implement your preparedness plan
  - Ensure that you have the right implementation tools
- Measure your progress and update your plan
  - Develop and track measures of resilience
  - Update your plan.

The following case studies describe how Maryland, Alaska, and California organized their own statewide climate change adaptation planning efforts. Executive summaries from the three adaptation plans that emerged are included in the Colorado Climate Preparedness Project database.[4]

Maryland Case Study

Governor O'Malley signed an executive order (EO) in April 2007, establishing the Maryland Commission on Climate Change (MCCC). This commission was charged with "developing a Plan of Action to address the drivers and causes of climate change, to prepare for the likely consequences and impacts of climate change to Maryland, and to establish firm benchmarks and timetables for implementing the Plan of Action".[5] The MCCC was comprised of experts from government departments and agencies, legislators, and representatives from academia, business, industry, and environmental groups—all tasked with advising the governor and the general assembly on matters related to climate change. The MCCC was divided into three working groups defined in the EO: the Adaptation and Response Working Group (ARWG), co-chaired by the Department of Natural Resources and the Department of Planning; the Greenhouse Gas and Carbon Mitigation Working Group, co-chaired by the Department of the Environment and the Maryland Energy Administration; and the Scientific and Technical Working Group, co-chaired by the University System of Maryland, the Department of the Environment, and the Department of Natural Resources (DNR).

3. Snover, A.K., L. Whitely Binder, J. Lopez, E. Willmott, J. Kay, D. Howell, and J. Simmonds, 2007: *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments,* in association with and published by ICLEI – Local Governments for Sustainability, Oakland, CA.
4. www.coloadaptationprofile.org
5. State of Maryland, 2007: Maryland Executive Order 01.01.2007.07, Commission on Climate Change, April 20. [Available online at www.gov.state.md.us/executiveorders/01.07.07ClimateChange.pdf, accessed November 29, 2010.]

Regarding adaptation, the MCCC was charged to "coordinate with the Maryland Departments of Natural Resources and Planning, and a comprehensive group of planners, emergency responders, and environmental organizations, as well as business and insurance representatives, to develop a strategy for reducing Maryland's vulnerability to climate change, with an initial focus on sea level rise and coastal hazards."[6] The ARWG created five subgroups to prioritize impacts and develop adaptation responses. These subgroups cover the following areas: existing built environment infrastructure; future built environment infrastructure; human health, safety and welfare; public awareness; and resources and resources-based industries.[7] The process, designed and facilitated by the Center for Climate Strategies (CCS), was a year-long planning effort that culminated in chapter 5 and appendix E of the Maryland Climate Action Plan.

The climate change impacts of greatest concern to the ARWG were sea level rise and coastal storms. This includes shore erosion, coastal flooding, inundation, impacts to barrier and bay islands, and higher water tables and saltwater intrusion. In support of ARWG activities, the MCCC Scientific and Technical Working Group assessed the 2007 Intergovernmental Panel on Climate Change global sea level rise projections, and regional land subsidence estimates, to provide a conservative estimate that by the end of this century, Maryland may experience a relative sea level rise of 2.7 feet under the lower emission scenario and as much as 3.4 feet under the higher emission scenario.[8]

Climate adaptation options followed a detailed format consistent across sectors by identifying the option description and design, exploring implementation mechanisms, identifying related policies and programs, estimating benefits and costs, and assessing feasibility issues. This format is very similar to that used by Alaska and described in that case study below.

All impacts and adaptation options addressed by the ARWG deal specifically with sea level rise and coastal storms, with the exception of a few human health issues. Chapters 6, 7, and 8 of the Maryland Climate Action Plan define Maryland's vulnerabilities to climate change, opportunities for state and federal coordination, and next steps. One of the next steps included a "Phase II of the *Comprehensive Strategy to Reduce Maryland's Vulnerability to Climate Change*," moving beyond coastal issues into other sectors affected by climate change. The Department of Natural Resources worked with the University of Maryland's Center for Environmental Science and Integration and Application Network to facilitate six sector-based adaptation work groups: agriculture, water resources, bay and aquatic ecosystems, forest and terrestrial ecosystems, human health, and growth and land use.[9] The Maryland Commission on Climate Change released its Phase II Strategy for Reducing Maryland's Vulnerability to Climate Change on January 24, 2011.[10]

Alaska Case Study

Governor Palin created the Alaska Climate Change Sub-cabinet in September 2007, under an administrative order[11] with the purpose of advising the Office of the Governor on the preparation and implementation of an Alaska climate change strategy. This sub-cabinet consists of the commissioners of the Department of Commerce, Community, and Economic Development; Department of Environmental Conservation (DEC); Department of Natural Resources; Department of Fish and Game; and Department of Transportation and Public Facilities. Representatives from the Office of the Governor and the University of Alaska served as official liaisons. The sub-cabinet then divided its responsibilities into four advisory groups: the Immediate Action Work Group, the Mitigation Advisory Group, the Adaptation Advisory Group (AAG), and the Research Needs Work Group.[12]

6. MCCAG, 2010: Maryland Commission on Climate Change, Maryland Climate Change Advisory Group. [Available online at www.mdclimatechange.us/, accessed November 29, 2010.]
7. State of Maryland, 2008: Appendix E, Maryland Climate Action Plan, Adaptation & Response Working Group Policy Option Documents. [Available online at www.mde.state.md.us/assets/document/Air/ClimateChange/AppendixE_Adaptation_Response.pdf, accessed November 29, 2010.]
8. Maryland DNR, 2008: Chapter 5: Comprehensive Strategy for Reducing Maryland's Vulnerability to Climate Change, Phase 1: Sea-level Rise and Coastal Storms. Report of the Maryland Commission on Climate Change Adaptation and Response Working Group, Maryland Department of Natural Resources, July. [Available online at www.mde.state.md.us/assets/document/Air/ClimateChange/Chapter5.pdf, accessed November 30, 2010.]
9. Maryland DNR, 2010: DNR Takes Lead in Mitigating the Effects of Climate Change with New Policy. [Available online at www.dnr.state.md.us/dnrnews/pressrelease2010/110110a.asp, accessed November 30, 2010.]
10. Maryland DNR: Fighting Climate Change to Secure a Sustainable Future for Maryland. [Available online at www.dnr.state.md.us/climatechange]
11. State of Alaska, 2007: AO 238, Administrative Order Establishing the Climate Change Sub-cabinet. [Available online at www.gov.state.ak.us/admin-orders/238.html, accessed November 30, 2010.]
12. State of Alaska, 2010: Climate Change in Alaska. [Available online at www.climatechange.alaska.gov/, accessed November 29, 2010.]

Although the Immediate Action Work Group tackled important issues related to adaptation, this case study focuses on the work of the AAG. Selected by the sub-cabinet, the AAG consisted of individuals representing a wide spectrum of expertise, from multiple state and federal agencies, local governments, the Alaska Native community, the University of Alaska, industry, and nongovernmental organizations (NGOs).

Prior to the first AAG meeting, Larry Hartig, chair of the Executive Sub-cabinet on Climate Change and commissioner of the State of Alaska's DEC, collaborated with the National Commission on Energy Policy (NCEP) to engage in background research on the anticipated impacts of climate change on Alaska and the Arctic. Because significant warming has already occurred in the Arctic and because a large network of researchers have focused their scientific work on the region, there was already a substantial amount of information on current and anticipated impacts from climate change. The NCEP/DEC collaboration included the development of a comprehensive list of climate change impacts for the AAG. But this collaboration also led to the development of criteria for assessing adaptation policy options, a suggested set of four technical working groups organized by impacts, a compilation of tools and policy levers available to the state for taking action, and a list of sample adaptation responses paired with a subset of the identified climate change impacts. In essence, the NCEP/DEC collaboration laid the substantive and analytical foundation for AAG's work.

Commissioner Hartig worked with the Center for Climate Strategies (CCS) and ICF International to begin organizing a public process to engage stakeholders in prioritizing climate change impacts and devising adaptation responses. The public process consisted of a hierarchical structure: the Climate Change Sub-cabinet that reported to the governor, AAG that reported to the sub-cabinet, and several technical working groups (TWGs) that reported to the AAG. The public process was first organized within four TWGs organized under the following general areas: health and culture, natural systems, public infrastructure, and economic activities (a fifth TWG relating to common themes was later added to address cross-sector adaptations). The initial four TWGs were derived from the NCEP/DEC collaboration with some minor modifications. The ultimate product of the TWGs was a set of three to six recommended policy actions, with extensive effort put into describing the policy option, detailing a proposed design for the policy, identifying implementation mechanisms, identifying related policies and programs, discussing the feasibility of the policy, and recognizing policy benefits and costs.

The TWGs investigated the previously identified climate impacts, identified impacts, categorized those impacts into subgroups, prioritized those impact subgroups, and developed adaptation options and write-ups for the prioritized impact subgroups. The AAG performed an advisory and review role for the TWGs, directing, reviewing, and approving the work of the TWGs before information was passed up to the sub-cabinet. Throughout the process, identified research needs were set aside and forwarded to the Research Needs Work Group. Development of the adaptation options and reports of the sub-cabinet was designed as a consensus-based process open to public participation, both at the AAG and TWG levels. The process sought a consensus to bring any recommendation forward, and outstanding issues were explicitly identified when consensus could not be achieved. Ultimately, almost all recommendations were approved unanimously by the respective TWG members and the AAG.[13]

California Case Study

Governor Schwarzenegger signed two executive orders (EOs) that jump-started California's climate change adaptation process. The first, signed in June 2005, focused predominantly on mitigating climate change and setting greenhouse gas emissions reduction targets. However, this EO also required the secretary of the California Environmental Protection Agency (CalEPA) to "report to the governor and the state legislature . . . on the impacts to California of global warming, including impacts to water supply, public health, agriculture, the coastline, and forestry, and [to] prepare and report on mitigation and adaptation plans

13. AAG, 2010: Alaska's Climate Change Strategy: Addressing Impacts in Alaska, Final Report, submitted by the Adaptation Advisory Group to the Alaska Climate Change Sub-cabinet, January 27; State of Alaska, 2010: Climate Change in Alaska. [Available online at www.climatechange.alaska.gov/, accessed November 29, 2010.]

to combat these impacts".[14] It also led to the development of the California Climate Action Team (CAT), coordinated by the secretary of CalEPA and including the secretary of the Business, Transportation, and Housing Agency; the secretary of the Department of Food and Agriculture; the secretary of the Resources Agency; the chair of the Air Resources Board; the chair of the Energy Commission; and the president of the Public Utilities Commission.

The second EO was signed in November 2008, formally initiating California's first statewide climate change adaptation strategy process.[15] This EO charged the California Natural Resources Agency, through the CAT, to coordinate with local, regional, state, and federal public and private entities to develop a state climate adaptation strategy. The first strategy, released in December 2009, was developed by five state agencies and nine departments, to plan for sea-level rise, wildfires, heat waves, floods, droughts, and other climate impacts. The strategy focused on seven sectors, including public health, biodiversity and habitat, ocean and coastal resources, water supply, agriculture, forestry, and transportation and energy infrastructure (agriculture and forestry were later combined into a "working landscapes" sector). The strategy also contained a section on "cross-sector collaboration" that includes adaptation strategies that cut across conventional state agency jurisdictions. Each sector was organized into a sector-based Climate Adaptation Working Group (CAWG) consisting of state agency experts with "an intimate knowledge of California's resources, environments, and communities, and also of the state's existing policy framework and management capabilities."[16] Each CAWG worked internally but also initiated a process of stakeholder consultation through public workshops and review opportunities.

Each CAWG was tasked to assess the impacts of climate change to their sector based on years of state-specific climate impacts research conducted largely through the California Energy Commission's Public Interest Energy Research Program. Using this broad base of information, each CAWG identified climate impacts on their sector for each of the following: increased temperature and extreme events, precipitation changes and extreme events, and sea-level rise. Each CAWG then identified and detailed five to 10 adaptation strategies for their sector. Due to the state financial crisis, each strategy included recommended "near-term" and "long-term" actions. Near-term adaptation strategies were organized by the necessity and/or ability to implement them by December 2010, largely within agencies' existing resource base. Long-term adaptation strategies addressed more expensive strategies and those with planning horizons on the order of 50 years or longer.[17]

Governor Schwarzenegger has already taken action on one climate adaptation strategy recommendation by announcing that the state will partner with the Pacific Council on International Policy's Task Force on California's Adaptation to Climate Change. The partnership will allow this panel of 23 prominent business, labor, government, and private sector leaders to act as the state's Climate Adaptation Advisory Panel. The panel has been tasked with building on the strategy final report by focusing on three areas: sea-level rise, water supply, and forest wildfires.[18] According to the recently released 2010 progress report, implementation has begun on a number of other key recommendations, comprehensive strategies, and sector-specific strategies proposed in the 2009 Climate Adaptation Strategy.[19]

A number of other noteworthy efforts complement California's activities under their Climate Adaptation Strategy. In March 2009, California's CAT, as required by the 2005 EO, published its latest report on climate change impacts and adaptation options, the Climate Action Team Biennial Report.[20] Also

14. State of California, 2005a: Executive Order S-3-05 [available online at www.gov.ca.gov/index.php?/executive-order/1861/, accessed November 29, 2010]; State of California, 2005b: Governor Schwarzenegger Establishes Green House Gas Emission Reduction Targets. Press Release, June 1 [available online at www.gov.ca.gov/press-release/1860/, accessed November 29, 2010].
15. State of California, 2008: Gov. Schwarzenegger Issues Executive Order Directing State Agencies to Plan for Sea Level Rise and Climate Impacts. Press Release, November 14. [Available online at www.gov.ca.gov/press-release/11035/, accessed November 29, 2010.]
16. State of California, 2009a: 2009 California Climate Change Adaptation Strategy Discussion Draft. CA Natural Resources Agency, August. [Available online at www.climatechange.ca.gov/adaptation/index.html, accessed November 29, 2010.]
17. Id.
18. State of California – California Energy Commission, 2010: Climate Adaptation Advisory Panel. [Available online at www.climatechange.ca.gov/adaptation/advisory_panel.html, accessed November 29, 2010.]
19. California Natural Resources Agency, 2010: 2009 California Climate Adaptation Strategy: First Year Progress Report to the Governor of the State of California. November. [Available online at www.climatechange.ca.gov/adaptation/index.html, accessed November 29, 2010.]
20. State of California, 2009b: Climate Action Team Biennial Report Draft. [Available online at www.energy.ca.gov/2009publications/CAT-1000-2009-003/CAT-1000-2009-003-D.PDF, accessed November 29, 2010.]

in response to the 2005 EO, the Preliminary Transportation Assessment, which assessed the vulnerability of state transportation systems to sea-level rise, was completed by the Business, Transportation, and Housing Agency and the California Department of Transportation.[21]

Conclusions

While the details of these adaptation planning processes are quite different, a number of important structural similarities can be seen in the case studies. All three states organized their efforts by climate impact or policy-relevant sector working groups. In all three cases, a separate working group was developed to address adaptation and that working group was largely separate from the mitigation working group when one existed. And all three efforts began with executive or administrative orders by the governor—a strong signal from the chief executive that served to enhance cooperation among state agencies.

Also, all three efforts engaged in what can be called a stakeholder-driven vulnerability assessment based on expert knowledge of impacted sectors and their policy context. This is different from a formal, model-driven vulnerability assessment that may utilize explicit projections of future climate as a prerequisite for discussing impacts (although California built upon years of state-sponsored analysis of climate change impacts and Alaska, years of research by the Arctic research community). All three states identified the highest priority climate impacts and focused on those. One notable difference between the cases is that California's effort was more intragovernmental, with stakeholder input on government-generated work products, while Alaska's and Maryland's efforts were more stakeholder-driven but managed, advised, and reviewed by government officials. All three efforts were problem oriented—focusing on impacts of clear concern to the state and to stakeholders. And all three efforts identified the existing roles and responsibilities of government for each affected resource as well as how to develop adaptation options that were targeted, feasible, and cost-effective.

While some of the specific climate impacts these states focused on are not relevant to Colorado, the processes used by the states to assess these and other impacts, and adaptation options to cope with them, should be instructive to efforts in Colorado to implement statewide adaptation planning.

Table 8-1: Comparison of Climate Change Adaptation Planning in Three States

State	Organization and Participants	Sectors[22]
Maryland	• **Maryland Commission on Climate Change**: experts from a number of government departments and agencies, legislators, and representatives from academia, business, industry, and environmental groups • **Adaptation and Response Working Group**: group of diverse stakeholders from across the state co-chaired by the Department of Natural Resources and the Department of Planning • **Technical Work Groups**: experts and stakeholders organized by sector	• Infrastructure • Health • Natural systems • Industry and economy • Public awareness
Alaska	• **Alaska Climate Change Sub-cabinet**: Department of Commerce, Community, and Economic Development; Department of Environmental Conservation; Department of Natural Resources; Department of Fish and Game; Department of Transportation and Public Facilities; and representatives from the Office of the Governor and the University of Alaska served as official liaisons • **Adaptation Advisory Group**: individuals with a wide spectrum of expertise from multiple state and federal agencies, local governments, the Alaska Native community, the University of Alaska, industry, and nongovernmental organizations • **Technical Work Groups**: experts and stakeholders organized by sector	• Infrastructure • Health • Natural systems • Industry and economy • Cross-sector
California	• **California Climate Action Team**: coordinated by the secretary of CalEPA and including the secretary of the Business, Transportation, and Housing Agency; the secretary of the Department of Food and Agriculture; the secretary of the Resources Agency; the chair of the Air Resources Board; the chair of the Energy Commission; the president of the Public Utilities Commission; and others • **Climate Adaptation Working Group**: Environmental Protection; Business, Transportation and Housing; Health and Human Services; the Department of Agriculture; the Department of Water Resources; California Natural Resources Agency; the State Water Resources Control Board; the Ocean Protection Council; the Department of Fish and Game, State Parks; the Department of Forestry and Fire Protection; the Department of Food and Agriculture; the Department of Public Health; and the Air Resources Board	• Infrastructure • Health • Natural systems[23] • Industry and economy • Cross-sector

21. State of California, 2009c: Vulnerability of Transportation Systems to Sea Level Rise: Preliminary Assessment. [Available online at www.climatechange.ca.gov/adaptation/documents/2009_Preliminary_Trans_Assessment.pdf, accessed November 29, 2010.]
22. The sectors have been renamed and grouped to facilitate comparison across states.
23. This broad sector includes biodiversity and habitat, ocean and coastal resources, water supply, and forestry.

9 Cross-Sectoral Impacts

While this report focuses on impacts to discrete sectors, in reality climate variability and change, and responses to those changes, extend across sector boundaries. Those occasioned by extreme events, like the 2002 drought, are obvious, but others cross-sector effects may be difficult to anticipate. Any comprehensive assessment of impacts and adaptations should attempt to identify processes and pathways by which climate effects interact. A sample of the cross-sectoral impacts that were identified either in our interviews or through review of the USGRCP and IPCC reports are shown in table 9-1.

Climate impacts on water resources—e.g., changes in runoff patterns, snowpack, and storage—were a significant source of impacts to the other four sectors examined in this report. Some cross-sectoral impacts are obvious: increased urban water demand in hot years could affect water available for irrigation, for example. Water shortages and higher water temperatures can be expected to limit production and efficiency at water-cooled electric generation stations, and hydroelectric generation efficiency is expected to be affected by changes in precipitation and streamflow. However, some of the impacts are more subtle; for example, climate change could affect the allocation of forage to livestock on BLM and USFS allotments, which in turn could affect the balance of livestock and wildlife use of available forage, and could alter demand for livestock feed. Drought not only increases wildfire, but decreases forest productivity and increases tree mortality.

Climate variability and climate change affect areas not examined in this report. For example, water resource changes can affect land use and transportation. Climate conditions affect air quality and health. Extreme events, like the 2002 drought, ripple through the economy in ways that can be hard to anticipate.

It is also important to recognize that climate impacts elsewhere, in the United States and internationally, can affect Colorado, through, for example, commodity prices and federal policy. This point was especially raised in the agriculture interviews given that sector's role in Colorado's export economy, but experience indicates that conditions outside of Colorado can affect tourism, land development and conservation, and forest management.

Table 9-1: Cross-sectoral Impacts Matrix

	Agriculture	Energy	Water	Wildlife, Ecosystems, Forests
Energy	Agriculture interest in greenhouse gas reductions through carbon sequestration in soils, and alternative energy (bio-mass and wind power) as potential adaptation measure.			
Water	Warmer and drier conditions will stress water supplies and, by implication, agriculture, especially irrigated farming. Irrigated agriculture is sensitive to runoff and thus in most areas also snowpack.	Increasing water scarcity expected to increase demands for energy needed to pump water throughout the state; reduced water supply expected to increase competition for water within the energy sector.		Wildfire and pine beetle kill impact water quality and cause erosion and deposition of sediment that reduce storage capacity. Reduction in overall streamflow, shift to earlier spring runoff, warming of stream and lake temperatures to affect aquatic organisms
Wildlife, Ecosystems, Forests	Climate change could affect the allocation of forage to livestock on BLM and USFS allotments, and the state has a large interest in how this might play out in terms of AUMs and the balance of livestock and wildlife use of available forage.	Large-scale solar and wind power installations pose threat to habitat integrity and ecosystem resilience due to large footprints on the land. Increased water temperatures would make aquatic ecosystems even more sensitive to cooling water discharged from power plants.		
Outdoor Recreation			Changes in the character and timing of snowpack and the ratio of snowfall to rainfall will influence winter 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.	Climate-induced changes in the frequency of fire or insect outbreaks across western North America will also affect park visitation.

10 Sectoral Options and Overarching Recommendations for Adaptation Planning in Colorado

This final chapter compiles adaptation options that emerged from the five sectors, and then identifies common themes from the interviews and background material. It concludes with concrete, overarching recommendations for how the state might proceed with climate adaptation planning.[1]

Sectoral Overview

The sectors examined in this report vary in their sensitivity to climate variability and change, and in the types of adaptations that might reduce vulnerability and impacts. A few factors, like water resources, market conditions, and federal policy, play a role in climate adaptation in most sectors, though differences remain. Additionally, the sectors interact in many ways, as suggested in the cross-sectoral impacts chapter, but also probably in ways that are difficult to discern in advance of significant climate extremes or change.

Several options for adaptation within each sector emerged either explicitly or implicitly from the interviews and background materials. While not intended as a comprehensive list of all possible adaptation options, table 10-1 compiles options that were identified and groups them by common themes. The list also includes any regulatory and policy options that were mentioned during the interviews.

1. It is beyond the scope of this project to prioritize or identify funding sources for options and recommendations mentioned in this report.

Table 10-1

Sectoral Options
Water
Coordination
• Establishing interagency groups to work on climate change adaptation and establishing links with the many federal climate change efforts centered in Colorado.
Informing the Planning Process
• Continuing to fund existing monitoring stations and adding stations in areas identified as critical; working with the state climatologist, NRCS, USGS, DWR-SEO and others to identify data needs; and impressing upon Congress the need for adequate funding for existing monitoring networks.
• Commissioning studies as well as acquiring knowledge from other sources on how demands will change in the future; encouraging planners to consider new types of extreme events in water planning for floods and droughts; and working with the research community to understand how extremes are changing.
• Continuing to fund process level hydrology studies; moving to include groundwater-surface water models; and working with researchers to investigate the performance of these models.
• Expending some effort to analyze results across studies to see if larger patterns can be discerned.
• Explicitly considering climate change in the SWSI process. Even qualitative analyses of the future to assist with planning will be useful if quantitative studies are too difficult.
• Having SWSI continue to support information-generating projects to assist with identifying trade-offs among the various potential solutions.
• Conducting additional research to understand how water right yields will change as the hydrograph changes; investigating how to create an Upper Basin-wide model that can handle compact curtailments properly. These are very sensitive issues and Colorado needs to perform this work without compromising its legal position or providing information deleterious to its cause to other states.
Stakeholder and Public Outreach
• Exploring modes for effective messaging, potentially through the Colorado Foundation for Water Education which is funded by the CWCB and is a valuable state partner for additional communication efforts.
• Relaying the strong link between water and climate change to the public.
Overcoming Planning Gaps and Barriers
• Encouraging planning for multiple futures; sponsoring a broad-based impacts and vulnerability study to support such activities; identifying “no regrets” or “least regrets” solutions should assist with planning.
• Describing uncertainties and critical assumptions in climate models clearly; undertaking regular updates of impacts and vulnerabilities as the science evolves.
Regulatory and Policy Options
• Continuing to monitor the interplay between federal laws and state water rights as climate change unfolds and as new or modified legislation is proposed.
• Providing input to the CEQ on the promulgation of rules and understanding these new rules will be critical. Future state work may be cited in EISs and should be compliant with any new rules to the best extent possible.
• Monitoring how national legislation such as the Clean Water Act and US Army Corps of Engineer regulations might be modified to include use of model projections for drought and flood planning.
• Recognizing the connection between the annual CWCB Construction Fund and Projects Bill and water-related climate adaptation.

Sectoral Options

Wildlife, Ecosystems and Forests

Coordination

- Promoting coordination among all state natural resource agencies.
- Expanding on the existing coordination mechanisms between state and federal agencies that have been established to deal with the mountain pine beetle infestation.
- Providing the state natural resource agencies with the mandate and staff resources to actively participate in the LCCs and CSCs.
- Appointing a state "adaptation czar" to coordinate the state response to climate change and establish consensus on the goals of adaptation.
- Engaging private landowners, who own and manage 60 percent of the state's land base, in climate adaptation, whether through existing programs administered by CSFS, DOW, and CWCB that support conservation measures by private landowners, or new programs.

Informing the Planning Process

- Coordinating across agency lines to develop the ecological data and models to bridge from the climate scenarios to climate impacts.
- Developing a statewide ecosystem/species vulnerability assessment so that adaptation priorities can be set in coordination with the federal agencies currently pursuing vulnerability assessments within Colorado.
- Monitoring the effects of the adaptation strategies that are implemented and adjust strategies as needed (i.e., "adaptive management").
- Promoting the continued information transfer from other agencies (USFS, USFWS) and entities (TNC, WAFWA) to state agencies.

Overcoming Planning Gaps and Barriers

- Promoting the continued development of institutional capacity at state agencies to carry out adaptation.
- Modifying governance documents and organizational structures as needed to ensure consistency with, and facilitation of, agency-wide adaptation planning.
- Providing, or encouraging the leveraging of, adequate financial resources to carry out adaptation planning.
- Encouraging the development of adaptation planning frameworks by state agencies that are consistent with those recently developed by the federal resource management agencies and the guidance from multi-agency and other synthesis reports on adaptation strategies.
- Promoting integrated resource management and adaptation planning at the landscape/basin scale (e.g. the Gunnison Basin pilot study) rather than the statewide scale or by jurisdiction.

Electricity

Coordination

- GEO could consider using its role as a direct arm of the governor's administration to facilitate energy-related adaptation efforts across multiple state agencies.

Informing the Planning Process

- State agencies and utilities could consider promoting or conducting research aimed at understanding how to accommodate greater penetration of renewable energy resources into Colorado's electricity grid, such as an ongoing GEO study examining the grid impacts of increased use of distributed generation such as rooftop photovoltaic systems, as suggested by GEO.
- The state could consider conducting a vulnerability assessment to determine whether current adaptive capacity in the energy sector is capable of meeting future climate challenges along with the impacts of climate mitigation efforts.
- Xcel Energy, GEO, and the PUC could examine the recommendations from the Colorado Smart Grid Task Force, along with Xcel's experiences with the SmartGridCity Project, and apply lessons learned to future efforts to incorporate demand response into utility planning
- GEO could consider working with Colorado universities, the National Renewable Energy Laboratory, and others to promote research into the impacts of climate change on renewable energy generation.
- GEO could consider continuing to promote cutting-edge research on emergency planning and climate mitigation impacts on the energy sector.

Sectoral Options

Electricity

Stakeholder and Public Outreach

- GEO, the PUC, and utilities could consider working together to further educate the public about the benefits of tiered pricing and other variable rate structures that could be useful as climate adaptation mechanisms, as suggested by the PUC.

Overcoming Planning Gaps and Barriers

- State officials could carefully consider the cross-cutting impacts of climate on both water and energy supplies and look to reduce water consumption in the energy sector.
- State agencies should expect continued pressure to reduce carbon emissions from the energy sector and could consider working hand-in-hand with utilities and generation companies to prepare for the impacts of greater use of renewable resources, electric vehicles, and other technologies on grid stability.
- State agencies could consider working together to develop a more comprehensive framework for integrating renewable energy development into land management and planning.
- The state could consider doing more to tie climate adaptation and mitigation mechanisms to economic development and job creation opportunities, as suggested by GEO.

Regulatory and Policy Options

- Amending state statutes or PUC rules to more proactively factor climate change adaptation into regulated utility resource planning, such as giving more weight to clean technologies in the selection of electric generation resources, as suggested by the PUC.
- Developing new laws and regulations pertaining to carbon emissions or other pollutants using flexible market mechanisms and designed to allow Xcel Energy to adequately recover the costs of compliance, as suggested by Xcel.
- Working with utilities to develop climate mitigation options that best fit Colorado's electricity supply structure in order to promote system stability and avoid rate spikes due to regulatory compliance costs.
- Having GEO use its position to facilitate cooperation among IOUs, rural electric cooperatives, and municipal utilities to help increase renewable deployment and promote efforts to understand climate vulnerabilities across the state's energy sector.
- Advocating for the inclusion of flexible, market-based mechanisms in federal greenhouse gas legislation.
- Quantifying the benefits of expanded dynamic metering and demand response programs and looking to promote them in order to improve resiliency of the grid and potentially reduce the need for peak generation capacity.

Agriculture

Coordination

- Tracking federal drought policy and federal provision of drought planning and information, for example, through the National Integrated Drought Information System (NIDIS).
- Examining the cross-cutting impacts of climate on both water and energy sectors, and how they affect agriculture.

Informing the Planning Process

- Strengthening support for an effective agricultural research program is one of the most logical investments in adaptive capacity in the face of an uncertain climate future.
- Conducting a vulnerability assessment to determine whether current adaptive capacity in the agriculture sector is capable of meeting future climate challenges along with the impacts of climate mitigation efforts.
- Developing tools that allow the state to monitor, simulate, and project the effects of climate variability and change on agriculture in the context of other changes, such as competition for land and water, and federal policy changes.
- Assessing potential climate-driven changes in national and international agricultural markets.
- Carefully tracking federal legislation and regulation trends, as well as business practices, that could make insurance and disaster relief programs (especially USDA disaster designations) more, or less, effective in the future.

Sectoral Options
Agriculture
Stakeholder and Public Outreach
• Strengthening support for an effective agricultural outreach program as one of the most logical investments in adaptive capacity in the face of an uncertain climate future.
Overcoming Planning Gaps and Barriers
• Climate change could affect the allocation of forage to livestock on federal (BLM and USFS) allotments, and the state should consider tracking how this might play out in terms of AUMs in a changing climate, and the balance of livestock and wildlife use of available forage.
Regulatory and Policy Options
• Colorado agriculture has a large interest in federal agricultural policy, changes in which might increase or decrease adaptive capacity. It is important to seek provisions of the next "farm bill" that engender a climate-resilient agriculture, especially regarding price supports (more oriented toward Western agriculture), in the conservation title and research titles, and in flexibility under the crop programs.
Outdoor Recreation
Coordination
• Using the federal/state collaboration that has been developed to address the mountain pine beetle as a basis to create an entity that will coordinate outdoor recreation adaptation across industries and government levels.
• Addressing the impact of increased summer outdoor recreation/tourism (and recreation in general) on transportation.
Informing the Planning Process
• More accurately quantifying the economic impact of outdoor recreation in the state.
• Compiling data on the economic impact of climate on recreation. Data might be gathered by the USFS research station or through the CTO's annual studies of tourism trends.
• Creating a clearinghouse of recreation impacts data that can be used in agency planning efforts.
Stakeholder and Public Outreach
• Providing visitors at State Parks visitor centers and other potential stakeholders with information about climate change.

Common Themes

The common themes that emerged from the five sectoral chapters—coordination among levels of government, informing the planning process, stakeholder and public outreach needs, and overcoming planning barriers and gaps—are discussed in detail in this section.

Coordination

Increased Coordination Among State Agencies

Because many climate impacts cross sectors and traditional agency boundaries, adaptation will require coordination across the state government for collecting and analyzing data, analyzing vulnerability to climate change, and developing and implementing adaptation strategies and monitoring the results. Given the inherent difficulties in coordinating across multiple agencies, gubernatorial-level leadership may be necessary to successfully carry out statewide climate adaptation efforts. To this end, the new governor could consider appointing a point person to establish consensus on the goals of adaptation and to coordinate the state's response to climate change.

In addition, state officials should identify mechanisms for: coordinating climate initiatives among agencies in the state to create permanent infrastructure for planning; promoting the continued development of institutional capacity at state agencies to carry out adaptation; and identifying additional organizational, regulatory, and budgetary barriers to adapting to climate change that are not identified in this report.

Coordination of the State with Federal, Regional, and Municipal Entities and Other Stakeholders

State officials should also facilitate coordination with non-state entities. Many interviewees emphasized the need for greater coordination with the federal government. The federal government's recent report on adaptation also recognizes the importance of coordinating adaptation within regions.[2] Growing federal activity focused on adaptation offers an opportunity to enhance state programs. It would be useful to develop adaptation planning frameworks by state agencies that are consistent with those recently developed by the federal resource management agencies and the guidance from multi-agency[3] and other synthesis reports[4] on adaptation strategies. It might also prove useful for state agency personnel to actively participate in regional federal projects like the National Assessment, the Department of Interior's Landscape Conservation Cooperatives (LCCs) and Climate Science Centers, and similar efforts by the U.S. Forest Service. The existing federal/state collaboration that has been developed to address the mountain pine beetle could be used as a model for forest and recreation adaptation.

Similarly, the state should consider collaborating with climate programs in relevant NGOs, such as The Nature Conservancy and Trout Unlimited. Colorado will also need to coordinate with adjacent states to address climate impacts on cross-state boundary matters, such as water resources and wildlife. Existing mechanisms, such as consultative efforts by the Western Governors' Association, provide a basis for such coordination.

Coordination with municipalities on adaptation will be useful in several ways: to enlarge the range of adaptation options by gleaning lessons from local programs, to enrich the vulnerability assessment with local and regional conditions, and to provide technical support to local governments that may not have the capacity to assess vulnerability to climate change or plan adaptations.

Informing the Planning Process

Monitoring

Monitoring is a critical element of climate adaptation, and includes both tracking climate variability and change at spatial and temporal scales that allow assessment of impacts and planning of adaptive responses, and monitoring the effectiveness of those adaptations. Some sectors already have strong monitoring systems in place (e.g., water), while for others very little is known about potential impacts (e.g., recreation). Many detailed suggestions for improved monitoring appear in the list of sectoral options, including increased efforts to track the impacts of climate variability on wildlife, ecosystems, forest health, and recreation.

Research

Additional research on the impacts of climate change on physical, ecological, economic, and legal systems was a need common to all sectors. Also, research is needed to anticipate the unintended consequences of climate adaptation and mitigation. An emerging example of research, monitoring, and assessment is the Department of Agriculture and CSU's Colorado Agriculture Simulation model of Colorado agriculture, which when completed will allow users to test alternative futures in terms of water, markets, technology, and other factors. There are lessons to be learned, too, in efforts such as the SmartGridCity experience that might be applied to future efforts to incorporate demand response into utility planning. The mountain

2. CEQ, 2010: Progress Report of Interagency Climate Change Task Force: Recommended Actions in Support of a National Climate Change Adaptation Strategy. U.S. Council on Environmental Quality, Washington, DC.
3. e.g., CCSP, *Preliminary review of adaptation options for climate-sensitive ecosystems and resources*.
4. e.g., The Heinz Center, 2008: *Strategies for Managing the Effects of Climate Change on Wildlife and Ecosystems*. The H. John Heinz III Center for Science, Economics, and the Environment, November, 42 pp.

pine beetle outbreak revealed monitoring gaps and research needs concerning, for example, potential effects on hydrology and recreation.

Vulnerability Assessment

The issues identified in the sector chapters—for example, in water supply, agricultural production, forest management, and winter recreation—begin to reveal the key vulnerabilities that Colorado faces. Building on the results of this project, the state should consider conducting a more complete impacts and vulnerability assessment centered on a range of plausible climate scenarios to prioritize Colorado's key climate threats and vulnerabilities. Such an effort could point to adaptations that could reduce costs and potential losses.

As a clearer picture of climate risks and opportunities is obtained, those findings should be made accessible and useful for state agencies and the public. The state should consider partnering with several other public, private, and NGO institutions to create an information repository to serve as a base for risk assessment and adaptation planning.

Stakeholder and Public Outreach

Communication between stakeholders and the state about climate change impacts and response strategies emerged as another important element of an overall adaptive strategy. Stakeholders can include people and groups with an interest in policy outcomes as well as people with insights into how climate affects resources or experience with the types of adaptations that reduce vulnerability (e.g., hunters, farmers, and water managers). Broader public awareness is especially important when climate variability causes changes in resource availability (e.g., water restrictions during droughts) and as climate trends affect long-term reliability and vulnerability of infrastructure and other resource systems.

Overcoming Planning Gaps and Barriers

A recurring theme across the sectors was the challenge faced by planners and managers as they attempt to incorporate climate change into decision-making. Even agencies that explicitly and successfully incorporate climate variability into planning are struggling with the incompatibility of the timescales of climate change, and the inherent uncertainty of long-term climate projections with existing planning regimes. The NRC report, *Informing Decisions in a Changing Climate*, recognizes the challenge that decision makers face "when predictive certainty is elusive and probabilistic information is all that is available." The report suggests using an uncertainty management framework that considers "the range of plausible futures and the key characteristics of each, the best estimates of the likelihood of each, and the likely magnitudes of the associated consequences."[5] Agencies might also begin by identifying lessons from climate variability and natural hazards management that could improve planning for climate change, and approaching climate change as a risk factor in multiple sectors. Decision-making in a changing climate could benefit from identifying key vulnerabilities and decisions that are sensitive to alternative climate futures; exploring alternative scenarios, decisions, and outcomes; and identifying and collaborating with key stakeholders and the information needs of decision-makers.

Overarching Recommendations

Attention to climate variability and change varies across agencies and sectors, yet overall there is widespread awareness of the value of reducing the state's vulnerability to climate impacts. But while the state continues to improve responses to droughts, floods, forest health, and other effects of typical climate variability, the large uncertainty that surrounds climate change poses a unique challenge of matching adaptive planning with the evolving science.

Planning for climate change in Colorado is in the very early stages. Some entities are awaiting a better understanding of the full social and environmental implications, while others are moving forward based

5. National Research Council, 2009: Informing Decisions in a Changing Climate. *Panel on Strategies and Methods for Climate-Related Decision Support*, National Academies Press, 188 pp, p. 20.

on current understanding and despite uncertainties.

In addition, the state is engaged regionally and nationally in climate assessments and efforts to shape policy so as to reduce vulnerabilities across multiple sectors. Moreover, Colorado can draw on a unique combination of in-state strengths in climate, energy, and natural resources research and management.

The state is in a good position to apply lessons from other states, and also to benefit from federal efforts like the many climate initiatives of the federal resource management agencies, emerging climate services structures, and the ongoing National Climate Assessment. If the state pursues an additional climate impact, vulnerability, and adaptation assessment, it makes sense to link these to the national assessment.

Our survey of the state-of-the-art in state adaptation planning in Maryland, Alaska and California indicated that those states tended to:

- focus on key threats in that state (e.g., sea level rise in Maryland; permafrost melting in Alaska);
- be initiated with strong leadership from the state executive and participation by multiple agencies, but then develop assessments and plans through stakeholder-based processes; and
- prioritize the timing, amount, and focus of adaptation projects in an effort to make efficient use of resources and to identify and address the most pressing needs.

Drawing on those examples, and the findings and options from the sector studies, we can distill a small number of overarching recommendations that could help the state move forward with an effective program to increase adaptation to climate variability and change. It was beyond the scope of this project to identify funding sources for or to prioritize recommendations.

- The governor should set the tone for climate adaptation efforts by providing leadership and resources.
- The governor should weigh the pros and cons of appointing a separate climate change adaptation coordinator. The current climate change coordinator position has largely focused on mitigation, reflecting the priorities of the Climate Action Plan.
- Adaptation efforts need flexibility across agencies in order to be successful. Such flexibility must be supported from the governor's office.
- Water supply impacts are somewhat known, cut across multiple sectors and could provide a focus for a statewide impacts and vulnerability assessment.
- Alternatively, a multi-sector statewide impacts and vulnerability study could focus attention on climate sensitivities in multiple sectors, including those where our understanding is weak.
- Climate science is constantly evolving and should be tracked and integrated into planning on a continuing basis to reflect updated research findings.
- Though more and better climate information is coming, we know enough about the likely direction and magnitude of climate change impacts relevant to many sectors to move forward with an initial cycle of adaptation planning in many areas.
- The state should actively engage with several federal initiatives including the new National Climate Assessment, the Landscape Conservation Cooperatives, and the Climate Science Centers, both to bring the state's insights to bear and to benefit from these larger efforts.
- To encourage additional exchange of information, as well as collaboration across a range of interests, the state should provide resources to maintain and enlarge the database and wiki developed as part of this project.

Appendix A

Interview Questions for State Agency Personnel

Introduction. This project is being undertaken by the Western Water Assessment for the State of Colorado. WWA is a joint effort between the Cooperative Institute for Research in Environmental Sciences at the University of Colorado and the National Oceanic and Atmospheric Administration's Earth System Research Laboratory. We are assessing the state's progress toward one of three goals set forth in Governor Ritter's Colorado Climate Action Plan: preparing the state to adapt to unavoidable climate change. ***The primary purpose of this project is to assist Colorado in continuing to prepare the state for climate variability and change by providing a catalog of climate vulnerabilities and current activities, personnel, products and projects from Colorado and other applicable entities along with policy relevant but not prescriptive recommendations for future action.***

We will be interviewing people from state agencies and cooperating NGOs to learn how the systems and stakeholders they work with are sensitive to both climate variability like floods and droughts as well as to possible long-term climate change. We are interested in understanding how your organization may be assessing the effects of climate variability and climate change on current and future operations and on the sectors of Colorado's economy that you work with. We would also like to know what, if any, actions your organization or the sectors you work with are taking to prepare for climate variability and climate change.

Please note that we are asking you to answer these questions on behalf of your organization and in terms of your organization's actions, plans, and areas of concern, not your personal opinions. We will identify interview subjects by organization and title (not name), but can remove your title from any public documents should you desire, and instead refer to the source of the material as a staff member of your organization. Please indicate whether you wish to have any identifiers removed. We will provide you with a draft of the report and ask that you make any corrections you desire concerning material attributed to you.

For the purposes of this survey, we define these terms as follows:

- **Climate** usually refers to average weather over a period of about 25-30 years.
- **Climate variability** refers to short-term deviations (between about a year and a decade) from the 25-30 year average. This is the range of conditions that can occur under today's climate, including periods of warmer/colder and wetter/drier conditions and extreme events such as droughts, floods, and heat waves.
- **Climate change** refers to a long-term (~25 year) increase or decrease in average measures of climate such as temperature, precipitation, etc. When we refer to climate change, we mean a future climate which is likely to be different from today's climate.

We are interested in **adaptation**, which are actions taken to adjust to climate change or climate variability. We distinguish adaptation from **mitigation** which refers to human actions to reduce greenhouse gases. We are not focusing on mitigation in this interview.

We anticipate that the interview will take approximately one hour. You may choose to withdraw from the interview at any time or decline to answer any questions. It would be helpful if you could bring along to the interview lists of people, organizations and documents in response to questions 12, 13, 15, and 18.

1. Please provide your name, title, and organization. What is your role within that organization?

2. Does your organization have a board of directors or advisory board? How are its members chosen? What is its decision making role within your organization?

3. Does your organization have a planning function? How far in the future does it plan for?

4. What changes in current conditions (population, income) are assumed in planning? What does your agency assume about the state of the climate within its planning horizon?

5. Other than budget and staff constraints, what are your organization's top 3 challenges related to the ability to achieve organizational goals in the future?

6. What are your organization's top three concerns about the impacts **climate variability** and **climate change** may have on people, organizations and [if appropriate] ecosystems and non-human communities within the sectors you work with?

7. Do **climate variability** and/or **climate change** affect your agency's operations and planning? If so, how?

8. Do you explicitly incorporate **climate variability** and/or **climate change** into agency plans, strategic thinking, or operations? If so, how?

9. Are you familiar with the Governor's climate action plan? Do you have any activities underway that could be considered in support of the Governor's climate action plan, or climate adaptation in general?

10. Would you like to include additional planning for **climate variability** and/or **climate change** in agency plans and operations? If so, how?

11. Are there barriers, uncertainties, or information gaps that hinder your ability to include **climate variability** and/or **climate change** into agency plans and operations?

12. Who are the key players in your organization who are engaged in climate issues? Who are the key players outside of your organization who are engaged in climate adaptation in your sector? Who should we talk to?

13. Have you sought any outside assistance or collaborations in responding to climate change? How have these relationships changed your organization's approach to climate/adaptation, and what are the aspects of these relationships that have been most beneficial or challenging?

14. Does your organization have a climate change adaptation plan under development? What is the timeline for completion?

15. Did your organization use any information, reports, tools, organizations, experts, or anything else in planning for climate?

16. Are there any measures your organization is taking today or in planning, whether related to climate or not, that could serve as climate adaptation measures?

17. Are there federal measures (laws, regulations, court decisions, etc) – or a lack thereof - that will impact your organization's actions regarding climate change adaptation? How might these be adjusted to assist climate change adaptation?

18. Are there useful documents regarding climate variability or change that we should review?

19. What is NOT being done to address climate variability and change that your agency/organization would like to do in the future or that your organization thinks should be done by other organizations?

20. Is there anything else regarding climate variability or change that you'd like to add?

Interview Questions for Non-State Agency Personnel

Introduction. This project is being undertaken by the Western Water Assessment for the State of Colorado. WWA is a joint effort between the Cooperative Institute for Research in Environmental Sciences at the University of Colorado and the National Oceanic and Atmospheric Administration's Earth System Research Laboratory. We are assessing the state's progress toward one of three goals set forth in Governor Ritter's Colorado Climate Action Plan: preparing the state to adapt to unavoidable climate change. ***The primary purpose of this project is to assist Colorado in continuing to prepare the state for climate variability and change by providing a catalog of climate vulnerabilities and current activities, personnel, products and projects from Colorado and other applicable entities along with policy relevant but not prescriptive recommendations for future action.***

We will be interviewing people from state and federal agencies, cooperating NGOs and others to learn how the systems and stakeholders they work with are sensitive to both climate variability like floods and droughts as well as to possible long-term climate change. We are interested in understanding how your organization may be assessing the effects of climate variability and climate change on current and future operations and on the sectors of Colorado's economy that you work with. We would also like to know what, if any, actions your organization or the sectors you work with are recommending the state take to prepare for climate variability and climate change.

Please note that we are asking you to answer these questions on behalf of your organization and in terms of your organization's actions, plans, and areas of concern, not your personal opinions. We will identify interview subjects by organization and title (not name), but can remove your title from any public documents should you desire, and instead refer to the source of the material as a staff member of your organization. Please indicate whether you wish to have any identifiers removed. We will provide you with a draft of the report and ask that you make any corrections you desire concerning material attributed to you.

For the purposes of this survey, we define these terms as follows:

- **Climate** usually refers to average weather over a period of about 25-30 years.
- **Climate variability** refers to short-term deviations (between about a year and a decade) from the 25-30 year average. This is the range of conditions that can occur under today's climate, including periods of warmer/colder and wetter/drier conditions and extreme events such as droughts, floods, and heat waves.
- **Climate change** refers to a long-term (~25 year) increase or decrease in average measures of climate such as temperature, precipitation, etc. When we refer to climate change, we mean a future climate which is likely to be different from today's climate.

We are interested in **adaptation**, which are actions taken to adjust to climate change or climate variability. We distinguish adaptation from **mitigation** which refers to human actions to reduce greenhouse gases. We are not focusing on mitigation in this interview.

We anticipate that the interview will take approximately one hour. You may choose to withdraw from the interview at any time or decline to answer any questions. It would be helpful if you could bring along to the interview lists of people, organizations and documents in response to the applicable questions.

1. Please provide your name, title, and organization. What is your role within that organization?

2. What are your organization's top concerns about the impacts **climate variability** and **climate change** may have on people, organizations and [if appropriate] ecosystems and non-human communities within the sectors you work with?

3. What recommendation would your organization make to the next governor about how the state of Colorado should incorporate planning for **climate variability** and/or **climate change** into its plans, strategic thinking, or operations?

4. What does your organization see as the barriers, uncertainties, or information gaps that hinder the state of Colorado's ability to include **climate variability** and/or **climate change** in its agency plans and operations? How can these barriers be overcome?

5. What resources (research, technical expertise, funding, etc) does or could your organization provide to the state of Colorado to assist in planning for climate variability and climate change?

6. Who are the key players in your organization who are engaged in climate issues? Who are the key players outside of your organization who are engaged in climate adaptation in your sector? Who should we talk to?

7. Are there state or federal measures (laws, regulations, court decisions, etc) – or a lack thereof - that will help or hinder the state of Colorado's actions regarding climate change adaptation? How might these be adjusted to assist climate change adaptation?

8. Is there anything else regarding climate variability or change that you'd like to add?

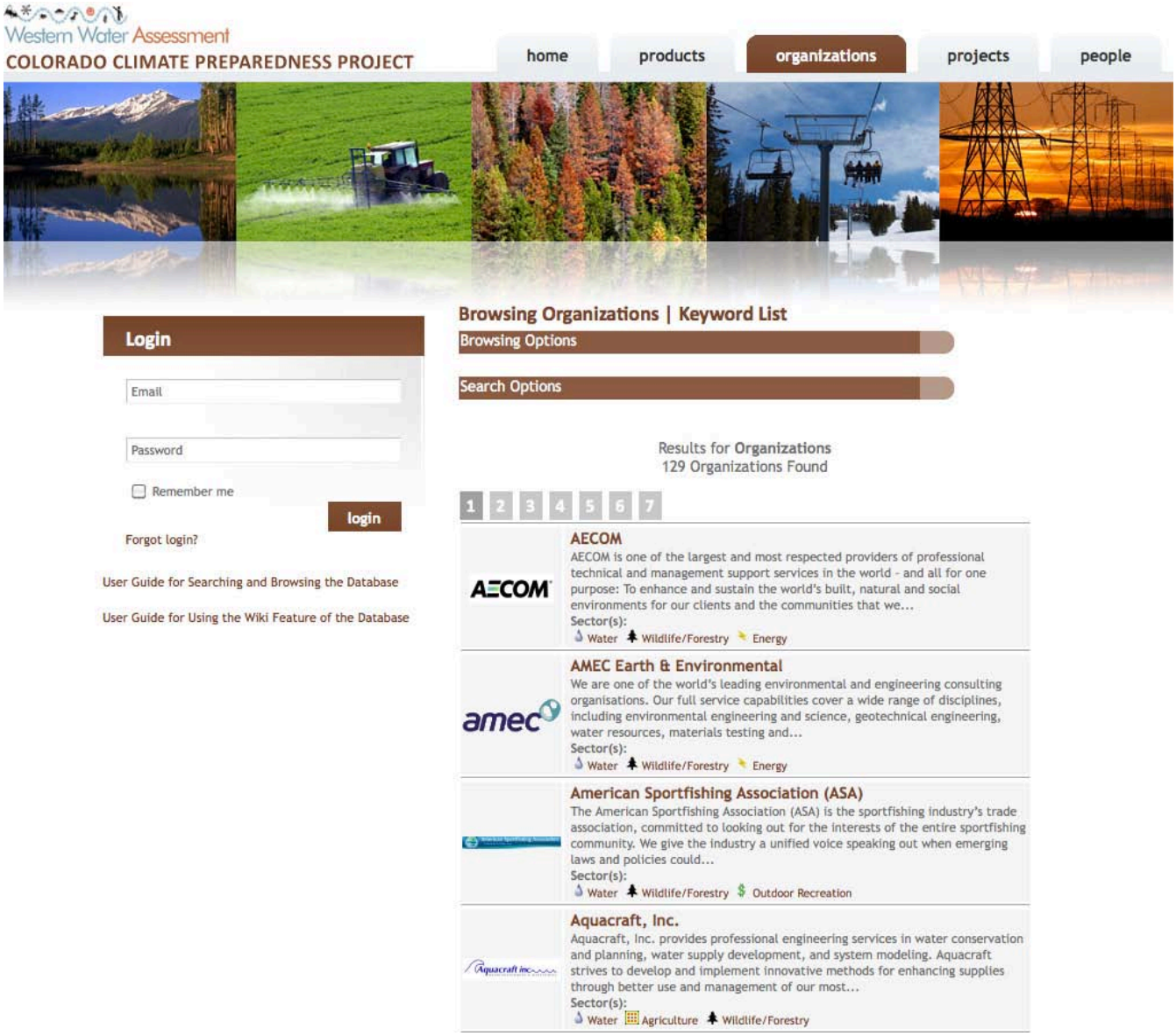
Appendix B

User Guide for Database

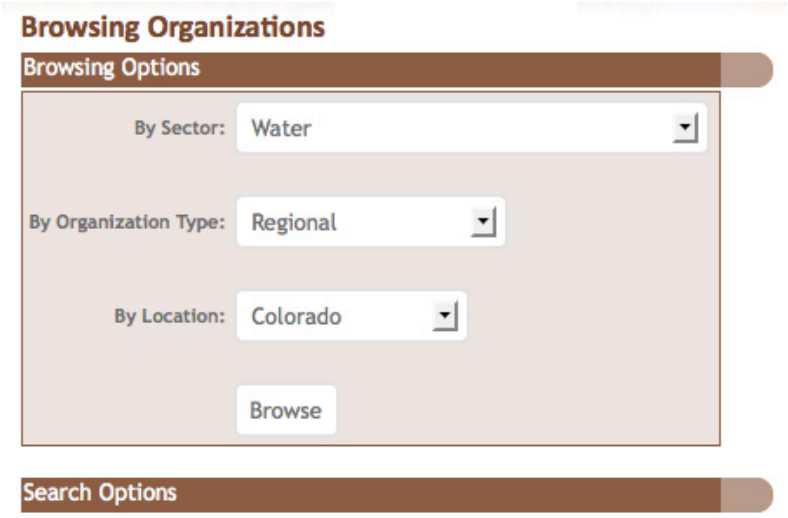
Welcome to the Colorado Climate Preparedness Project online database located at www.coloadaptationprofile.org. This tutorial will walk you through the two main tools available to access information on the database: searching and browsing. We will use organizations as an example, but the products, projects, and people sections of the database have similar if not identical functions.

At the top of the homepage at www.coloadaptationprofile.org are four tabs corresponding to the four types of entries that can be searched or browsed.

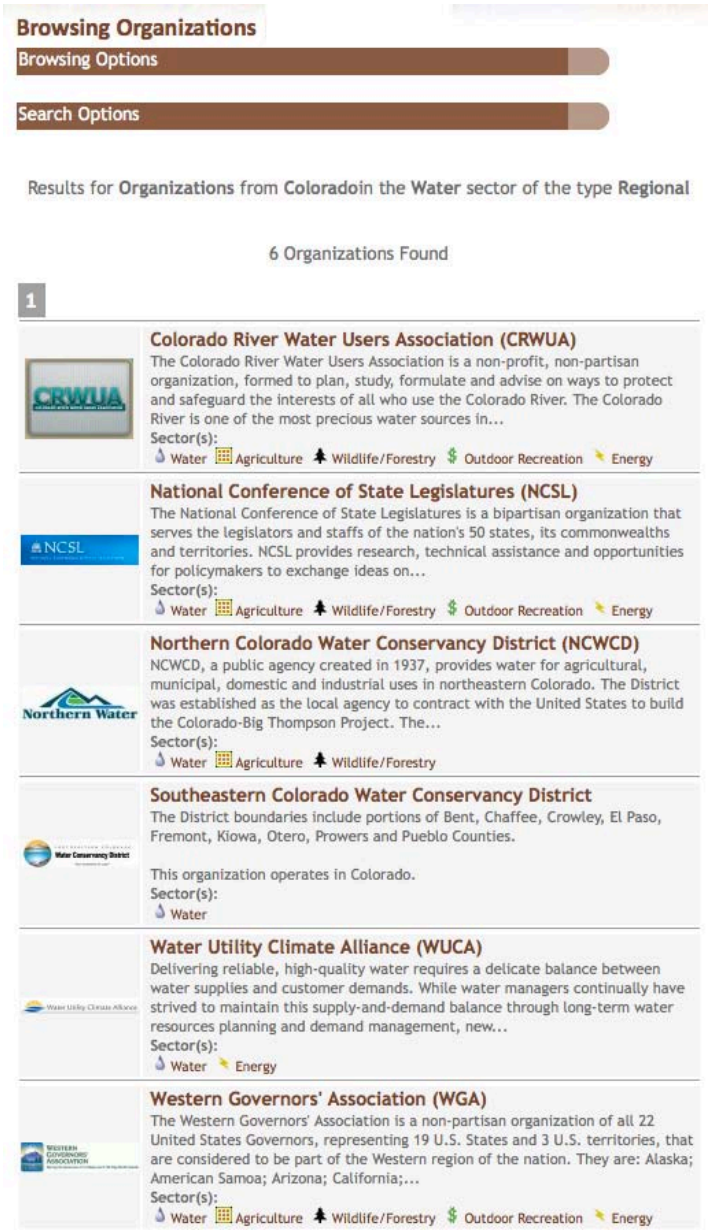
To begin, click the "Organizations" tab at the top of the page. You are then presented with the following screen:



Browsing allows you to display, for example, all organizations that deal in water, operate in Colorado, and are regional in focus, as demonstrated below:



The results of this browse are shown below:



The "Products" tab allows browsing by sector, type of author (e.g., local, state or federal government, NGO), and by whether the product is from Colorado or elsewhere. Thus, one may browse for all products created by state government within Colorado, for example.

Finally, the "People" browsing option allows sorting based on sector and whether individuals are employed by the state of Colorado.

The search function allows you to search for any term in an organization's name or name and description (products, projects, and people searches all look slightly different based on the types of information the entries contain). For example, a search for "water" within an organization's name returns 17 results:

Most organizational acronyms (NOAA, WWA, CU) are included in parenthesis after the full name of an organization, project, or product to facilitate searches.

Appendix C

Conclusions from *Climate Change in Colorado* Executive Summary

In 2008 the Colorado Water Conservation Board released the *Climate Change in Colorado* report. The report contained six chapters: (1) an introduction, (2) a look at trends in historical data, (3) a climate model primer, (4) a look at the attribution of recent climate changes, (5) a climate projections chapter and (6) a brief discussion of the implications of the findings. The Executive Summary contained numerous significant conclusions, all of which are reproduced here.

- 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.

- 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."

- 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.

- 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 percent 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

- 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.

- 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.

- 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.

- 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 percent) for Colorado's high-elevation snowpack (above 8200 ft) within the same timeframe.

- 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.

- 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.

- 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 percent to 20 percent by 2050 compared to the 20th century average, although one statistical streamflow model projects a 45 percent 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.

- 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.

- 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.

Appendix D

Colorado Climate Center

The Colorado Climate Center was established by the state in 1974 through the Colorado State University Agricultural Experiment Station to provide information and expertise on Colorado's complex climate. Through its threefold program of climate monitoring (data acquisition, analysis, and archiving), climate research and climate services, the center is responding to many climate related questions and problems affecting the state today.

Colorado's current state climatologist, Nolan Doesken, is responsible for tracking temperature, precipitation and humidity trends; conducting research; and providing information about Colorado's climate to decision makers such as the State Water Availability Task Force as well as the public. Past state climatologists are Dr. Thomas B. McKee who served from 1974 to 1999, and Dr. Roger A. Pielke, Sr. who served from 1999 to 2006.

http://ccc.atmos.colostate.edu

Abbreviations Used in this Report

AUM: Animal unit month

BLM: Bureau of Land Management

CalEPA: California Environmental Protection Agency

CAT: California Climate Action Team

CCPP: Colorado Climate Preparedness Project

CCRP: Climate Change Response Program

CCS: Center for Climate Strategies

CCSP: Climate Change Science Program

CCTAG: Climate Change Technical Advisory Group

CDA: Colorado Department of Agriculture

CDPHE: Colorado Department of Public Health and Environment

CDOT: Colorado Department of Transportation

CRWAS: Colorado River Water Availability Study

CSC: Climate Science Centers

CSFS: Colorado State Forest Service

CU: University of Colorado

CWCB: Colorado Water Conservation Board

CWI: Colorado Water Institute

DARE: Colorado State University Department of Ag and Resource Economics

DEC: Department of Environmental Conservation

DMRPC: Drought Mitigation and Response Planning Committee

DNR: Department of Natural Resources

DOW: Colorado Division of Wildlife

DWR: Colorado Division of Water Resources

EPA: Environmental Protection Agency

ERP: Electric Resource Plans

EVs: Electric vehicles

GEO: Governor's Energy Office

IBCC: Interbasin Compact Committee

IOUs: Investor-owned utilities

IPCC: Intergovernmental Panel on Climate Change

JFRCCVS: Joint Front Range Climate Change Vulnerability Study

LCCs: Landscape Conservation Cooperatives

LWCF: Land and Water Conservation Fund

MCCC: Maryland Commission on Climate Change

MPB: Mountain pine beetle

NCEP: National Commission on Energy Policy

NEPA: National Environmental Policy Act

NGOs: Nongovernmental organizations

NIDIS: National Integrated Drought Information System

NOAA: National Oceanic and Atmospheric Administration

NPS: National Park Service

NRCS: Natural Resources Conservation Service

OEDIT: Office of Economic Development and International Trade

PUC: Public Utilities Commission

REAs: Rapid Ecoregional Assessments

RICDs: Recreational In Channel Diversions

RMCO: Rocky Mountain Climate Organization

RMFU: Rocky Mountain Farmers Union

SCORP: Statewide Comprehensive Outdoor Recreation Plan

SWAP: State Wildlife Action Plan

SWSI: Statewide Water Supply Initiative

TNC: The Nature Conservancy

TU: Trout Unlimited

USFS: US Forest Service

USGCRP: US Global Climate Change Research Program

USGS: US Geological Survey

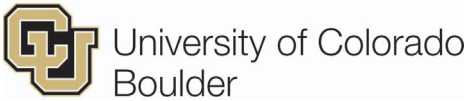
USFWS: US Fish and Wildlife Service

WAFWA: Western Association of Fish and Wildlife Agencies

WGA: Western Governors' Association

WUCA: Water Utility Climate Alliance

WWA: Western Water Assessment



Colorado Climate Preparedness Project
www.coloadaptationprofile.org