STRATUS CONSULTING

Boulder County Climate Change Preparedness Plan
Draft

Prepared for:

Boulder County and the City of Boulder

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Prepared by:

Stratus Consulting Inc.
PO Box 4059
Boulder, CO 80306-4059
303-381-8000

1920 L St. NW, Suite 420
Washington, DC 20036

Contact:

Jason Vogel

December 22, 2011
SC12586

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1. Introduction

Climate already affects a variety of resources managed by Boulder County, the City of Boulder, and other local municipalities. As an example, prolonged dry spells in the past decade have contributed to major wildfires on public lands that have threatened lives, impacted public health, damaged county and city property and infrastructure, and caused accelerated hill slope erosion that has polluted streams and water supplies. Resource managers working at county departments and throughout other jurisdictions already face challenges posed by the variability of climate across Boulder County.

Climate change, however, could pose a host of new challenges and require managers to pay much greater attention to resource vulnerabilities. These new challenges are most evident in planning efforts. In general, most resource management planning around climate relies on assumptions grounded in existing climate records that date back generally no further than the late 1800s or early 1900s. However, tree ring data, climate model projections, and other sources of climate information indicate that the climate system of the future could be quite different from the past 100 years. Thus the plan presented here is intended to systematically consider the potential effects of projected climate changes on city and county planning and management processes and to identify opportunities for adaptive planning efforts to proactively address the challenges and opportunities posed by changing climate conditions in Boulder County. **The objective of this plan is to assist county and city departments that manage climate-sensitive resources and assets to achieve their departmental objectives in the face of challenges posed by anticipated future changes in the climate of Boulder County.**

Jurisdictions throughout the world have increasingly realized that the climate is already changing and that the planet is already committed to further changes due to increasing global fossil fuel use for energy production and transportation. Even if humans were to immediately stop producing greenhouse gases (GHGs), the long duration of carbon dioxide (CO_2) and other GHGs in the atmosphere means that the planet would still experience warming over the coming decades. Thus, Boulder County and the City of Boulder have also realized that despite their best efforts to reduce GHG emissions, climate change impacts are inevitable and have the potential to exacerbate many of the challenges faced by Boulder County and its municipalities. This plan is the first step in preparing for such impacts.

Potential impacts could include more frequent droughts and flash floods, greater spread of vector-borne diseases, and increased heat waves and wildfires. Warmer springtime temperatures would cause snowpack to melt earlier in the year, reducing the overall amount of water stored as snow, which will shift peak flows to earlier in the year and decrease runoff during the dry summer months. Combined with more intense precipitation events, earlier snowmelt might also increase the risk of flash flooding. Potential challenges in storing water for municipal supplies will be exacerbated as increased temperatures and prolonged dry spells create more intense water demands. Reductions in storage and more frequent, intense, and longer duration droughts will severely impact the ability to provide adequate municipal water supply. Instream flows will also be reduced more severely and frequently, with subsequent impacts to water quality and ecological resources and related benefits such as recreation and tourism. Additionally, higher temperatures and fewer days with precipitation will likely increase the frequency and severity of heat waves, episodes of poor air quality, wildfire risks, and associated human health impacts.

Adding to the complexity of managing the impacts of climate change is the uncertainty inherent in climate science. Although scientists are reasonably confident in the direction of temperature changes, the magnitude of change remains uncertain. For other changes, like precipitation, both the direction and magnitude of change are uncertain. This means that Boulder County and its municipalities are facing an uncertain range of possible future climate conditions with ensuing complications in identifying proactive management responses that are robust yet cost-effective across a potentially wide range of future climate conditions and design requirements.

To address this complexity, this plan is aimed at improving the "resilience" of the county and its municipalities in the face of climate change. Resilience implies an ability to plan for and deal with the impacts of future changes without imperiling major departmental or other functions. In the real world, this means that water supply entities could handle both short-term problems like drought and long-term changes like a shift in snowmelt timing. Rather than simply trying to anticipate future changes and adapting to those expectations, a resilient county and its municipalities consider the likelihood and possibility of a number of possible future impacts and make operations, planning, and management flexible enough to avoid major disruptions from climate change. Although bolstering resilience is the overarching strategy in this plan, the term "adaptation" is also used to refer to opportunities to plan for the most likely future changes.

Structure of the preparedness plan

In light of potential climate change impacts described in research reports issued by institutions including the Intergovernmental Panel on Climate Change (IPCC) and the United States Global Change Research Program, Boulder County and the City of Boulder began this planning effort to assess the challenges, capabilities, and opportunities for Boulder County, the City of Boulder, and neighboring municipalities to manage the impacts of climate change. This plan focuses on four key sectors: water supply, emergency management (EM), public health, and agriculture and natural resources. Additional sectors might be evaluated in future plan updates.

This plan identifies the potential impacts of climate change, explores the implications of these changes in the context of resource management institutions, and outlines opportunities for adaptation planning efforts. It is not intended to be viewed as a requirement for additional planning efforts on top of the already significant planning and management responsibilities facing county and municipal departments. Rather, it is intended to serve as a resource for county and municipal planners as they integrate climate change, in addition to other concerns, into their ongoing planning efforts.

Thus, unlike many planning documents, this plan is not meant to stand on its own. It addresses multiple issues within multiple departments and across multiple jurisdictions. Such a document, instead of dictating a comprehensive climate resilience policy, can be more effective by expanding the focus of attention of resource managers, management administrators, and elected and appointed officials within and across departments and between and across levels of government.

To accomplish this goal, the plan has been designed so that each chapter can stand alone and provide those interested in a particular sector with information on that sector. If, for example, a citizen or public health planner is primarily interested in the effects of climate change on public health issues, he or she need only read the public health chapter. This allows resource managers, their administrative leadership, and their advisory boards to extract the information most relevant to their decisions without having to read the entire plan. But it does mean that there is some duplication of information in the plan, especially between the impact discussions in the science chapter and the impact discussions in each of the four sector chapters. Despite this overlap it is recommended that users of specific chapters also read Chapter 2 of the plan, as this provides a useful context for all other chapters.

Chapter 2 provides a state-of-the-science overview of projected climate change along the Colorado Front Range and Boulder County in particular. Although there is still significant uncertainty about the magnitude of various potential future changes in our climate system, especially due to the diverse landscapes and habitats ranging from the high elevation prairie to the Continental Divide, planners can benefit from an understanding of what is and what is not known about how increased GHG emissions could affect the climate in this region and how those changes in climate can impact human and natural systems.

Planning for and being able to adapt to uncertain changes in a future climate, however, is critical to being prepared for this change and managing associated risks. Thus, Chapters 3–6 contain policy-oriented assessments of opportunities to integrate climate change and adaptation planning into city and county decision-making processes, management approaches, and existing planning documents. In other contexts, adaptation has been found to work best when climate change impacts are considered in an integrated fashion along with other considerations such as changes in population, land use, and citizen preferences. At its core, adaptation is essentially about planning for change – changes in climate but also changes in other factors that have important influences on resource and hazards management (HM). By recognizing and preparing for the consequences of climate change, we can increase our resilience to the future impacts of other stressors that might not necessarily be directly linked to climate change processes.

Because of the substantial uncertainty about the nature and timing of the impacts of future climate change, adaptation and resilience planning are most successful when incorporated into routine planning and management decision-making. Successful implementation of this plan, therefore, entails understanding how the county and its municipalities are currently managing and conducting planning for resources that might be affected by climate change. A successful plan must also focus on adapting processes to meet new challenges. For example, given the many uncertainties associated with climate change, adaptive management will be needed to integrate new information as it becomes available, to identify policy options that are robust under a wide range of potential climate futures, and to set the stage for expansion of climate considerations into other sectors that are not covered in this plan.

This plan is not intended to serve as an in-depth assessment of all climate impacts and adaptation opportunities relevant to all county and municipal departments. Thus, each sector chapter contains recommendations for further study or action that could serve to improve the ability of county or municipal staff to prepare for climate change.

The overall county strategy for meeting the challenge of future climate change and implementing the plan is also outlined in the final chapter. County and municipal staff should view this document as setting an overall climate resilience agenda, identifying opportunities for incorporating adaptation into existing management and planning, and establishing a process for future efforts.

2. Overview of Boulder County Climate and Change

This chapter briefly overviews what contemporary science can tell us about possible climate change impacts on Boulder County. We begin with a summary of the most recent generation of global climate projections and their uncertainties to provide context and emphasize that climate models cannot provide perfect forecasts of the future. We then describe the observed (i.e., historical) climate of Boulder County over the 20th century and how major climatological variables are projected to change over the rest of the 21st century. Finally, we describe how projected climate change might impact the four sectors covered in this plan: water supply, EM, public health, and agriculture and natural resources.

Summary of climate change projections and impacts for Boulder County

- Average temperatures are expected to rise by ~ 2–3°F by 2030 and ~ 3.5–5.0°F by 2050, with more warming in summer than in winter.
- There is more uncertainty in projections of precipitation changes compared to temperature changes.
- Warmer temperatures will lead to a greater fraction of precipitation falling as rain instead of snow.
- Warmer spring temperatures will lead to earlier snowmelt, runoff, and peak natural streamflow.
- Warmer temperatures during the growing season lead to increased use of water by natural vegetation and increased crop irrigation requirements.
- There is potential for decreased annual streamflow volume in Boulder County watersheds and in the Colorado River, according to existing studies.
- Climate change has the potential to result in stronger extreme summer precipitation events.
- Since the mid-1980s, warmer summers have increased the duration and intensity of wildfires across the western United States, a trend that is likely to continue.
- In forested and other ecosystems, species composition is likely to change with potential loss of high-elevation alpine habitat, but, overall, the direction of ecosystem changes is unknown at this point.

- Although heat waves will likely become more frequent, there is also the potential for continued cold outbreaks in winter, even in an overall warmer climate.
- Warming temperatures might result in an increase in air pollution and water- and foodborne illnesses, though actual outbreak rates are dependent on a number of factors.
- Certain crops might benefit from additional CO_2 and a longer growing season, but above certain temperature thresholds, the productivity of some crops declines and other crops require additional water to avoid crop failures.

2.1 The Global Context

The Earth has unequivocally warmed over the past century, and this warming is very likely due to the accumulation of human-caused GHGs, such as CO_2, in the atmosphere (IPCC, 2007). This warming has taken place almost everywhere over the continents (Compo and Sardeshmukh, 2009), which strongly suggests that there is a global cause, rather than a mere coincidence of weather patterns that would result in patches of warming and cooling.

General Circulation Models (GCMs) that project future climate show that the northern tier of the United States is likely to get wetter while the southwestern states get drier (IPCC, 2007). Colorado lies between these two regions, and climate models generally show that the state will experience an increase in winter precipitation, especially in the northern part of the state, and a decrease in spring precipitation. Some models show a net annual increase in precipitation, while others show a net annual decrease. Regardless of the results of these projections, Colorado will continue to have considerable variability of precipitation from year to year and from decade to decade. Climate models are in agreement that Colorado and much of the western United States are expected to warm in the future, continuing trends seen over the past 30 years (Ray et al., 2008).

It should be noted that projections of future climate are inherently uncertain. This uncertainty arises from three main sources: the amount of future emissions of GHGs, the strength of the climate's response to GHGs, and climate variability (Hawkins and Sutton, 2009). First, future emissions of GHGs and changes in other factors that affect the global climate depend on many societal factors. Climate scientists evaluate this source of uncertainty through the use of emissions scenarios with differing socioeconomic, technological, and demographic assumptions. The second source of uncertainty is the strength of the response of the climate to the increasing GHGs. Scientists evaluate this source of uncertainty by looking at the climate projections from different climate models produced by different modeling centers around the globe. The GCM simulations that are the basis for the climate projections in this chapter capture only the response to GHGs, global and regional aerosols (suspended particles), and known solar variations. They do not include the climate response to local factors such as changes in irrigated crop acreage, urbanization, and dust deposition on snow. These influences on local climate drivers can be studied using specialized regional climate and hydrologic models. While few of these specialized studies that are in the scientific literature are of relevance to Boulder County communities, we have made reference to those that do.

Finally, the third uncertainty about future climate arises from the natural variability of the climate on all time scales. Natural year-to-year and decade-to-decade variability would happen even in the absence of increasing GHGs. Increasing GHGs shift the baseline about which climate varies, and it can change the character of the variability. However, climate science has not reached a consensus as to how the natural modes of climate variability that affect Boulder County, such as El Niño/La Niña-Southern Oscillation (ENSO), might change in the future. El Niño events have produced exceptionally wet weather in the region while La Niña has been associated with drought cycles and episodes of catastrophic wildfire. Because of natural variability from decade to decade, periods of slowly increasing or even decreasing temperatures can be followed by periods of rapid increase. For precipitation, the projected trends in Colorado are relatively small compared to the variability, so decades of observations might be needed before a long-term trend in Boulder County's precipitation becomes clearly evident.

For the purposes of this plan, we have primarily examined climate projections based on the IPCC "A2" emissions scenario, which assumes continued high levels of GHG emissions (Nakicenovic et al., 2000). This A2 scenario will therefore pose greater challenges for human and natural systems to adapt to climate change than lower emissions scenarios – particularly during the second half of the 21st century. For more information on climate modeling and the translation of global climate effects to local geographies, we strongly recommend Chapter 3, The Science of Climate Modeling, in *Climate Change in Colorado* (Ray et al., 2008).

2.2 Observed Climate

Boulder County has a diverse climate. An understanding of how our climate has varied in the past provides a useful context for understanding climate projections. It allows us to compare the magnitude of the projected trends to past variability and to look for consistency in the projected and past trends. Understanding our climate also allows us to focus on those aspects of the climate – such as winter and spring storms – that may have different trends in the future.

Topography has a profound influence on Boulder County's climate. Perhaps the most obvious effect is the decrease in average temperature from the plains to the foothills and up to the Continental Divide. From the county's eastern border around 5,000 feet, elevation generally increases toward the west, where the plains meet the Front Range of the Rocky Mountains. Here elevations rise abruptly to the Foothills and then again to the high peaks of the Front Range, including the Continental Divide and Longs peak at over 14,000 feet. During the summer months, this topographic contrast induces thunderstorms in the county almost any day that humidity is sufficiently high. There are large seasonal swings in temperature and significant day to night changes. During summer there can be very hot days on the plains, where relatively low humidity favors rapid evaporation of water and high water use by plants (known collectively as evapotranspiration). In the foothills and mountains of the county, temperatures typically drop quickly at night, and in the mountains freezing temperatures are possible every month of the year. Topographic variations can also create numerous microclimates in Boulder County that result from cold air pooling in areas of low elevation, temperature inversions (warm air overlying cold), rain shadows, warm Chinook winds, and other processes.

The amount and seasonality of precipitation is also correlated with elevation (Figure 2.1). Precipitation in the plains and foothills is dominated by two periods – a peak in April and May, due mainly to springtime upslope storms, and a second peak in July and August due mainly to convective storms. In the lower elevations of the county, there is a pronounced minimum in precipitation during the winter months. Precipitation in the high mountains (roughly west of the Peak-to-Peak Highway) has a much larger contribution from the winter storms than elsewhere in the county. As a consequence, the annual volume of natural flow in Boulder Creek (prior to storage and diversion) is highly correlated with that of the Colorado River headwaters, which also get a substantial amount of water from these winter storms (City of Boulder, 2004).

The long-term record (1905–2010) of three common climate parameters – average daily minimum temperature, average daily maximum temperature, and monthly total precipitation – is shown in Figure 2.2. We show the averages for all of Boulder County – plains, foothills, and mountains. A good deal of caution is warranted in interpreting the long-term trends in these data.[1] These data are derived from the PRISM (Parameter-elevation Regressions on Independent Slopes Model) dataset, which combines data from many available observing stations using statistical techniques. The PRISM method creates a high resolution grid (approximately 2.5 miles on a side) of monthly temperatures and precipitation for the conterminous United States. The grids over Boulder County are then averaged together. Minimum temperatures show an increasing trend, while maximum temperatures have a less prominent trend, with comparatively large decadal variability and notably warm years in 1934 and 1954. Precipitation is characterized by large variability with a relative absence of any long-term trend.

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1. Boulder County's weather data for the past century, like much of the weather data in the United States, was not gathered with the intent of measuring long-term trends. For example, the Boulder Cooperative Observer Network (COOP) weather station has moved several times, even in the past couple of decades, making it difficult to understand whether a trend in the data is due to climate change or factors specific to a new station site. In contrast, the Longmont COOP station has a long and relatively stable observing record, but observations there were discontinued in 2005. Long-term precipitation trends are generally less sensitive than temperature trends to small station moves, and precipitation measurement techniques have been relatively consistent over time. The early part of this record relies more heavily on the statistical relationship between regional temperatures and those in Boulder County due to the smaller number of observations available.

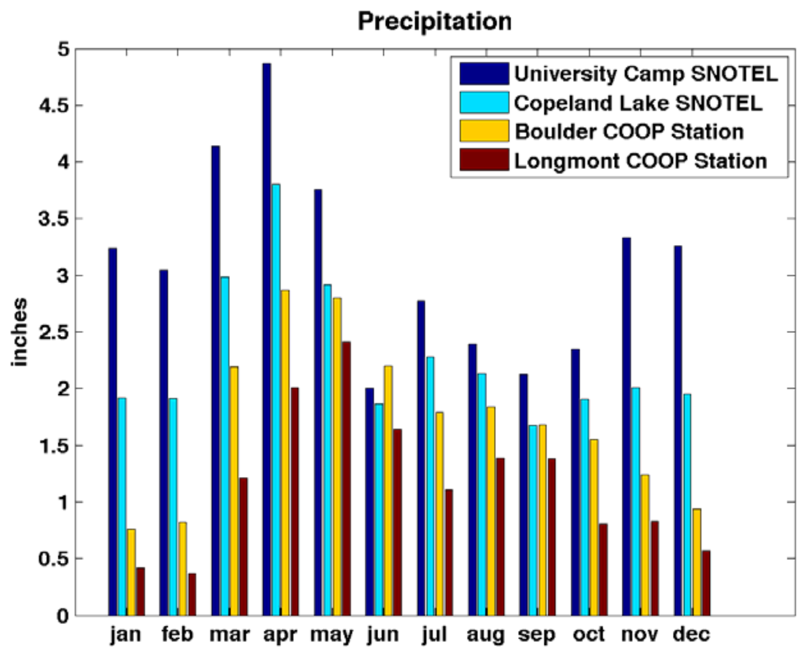

Figure 2.1. Elevation affects the amount and timing of precipitation in Boulder County. This graph shows monthly average precipitation at four weather stations in Boulder County: University Camp SNOTEL (10300'), Copeland Lake SNOTEL (8600'), Boulder COOP (5480'), and Longmont 2SE COOP (4950'). Note that there is greater precipitation in November – March at the higher elevation stations. 20–30 year averages are shown, depending on data availability at each observing station.

Sources: USDA Natural Resources Conservation Service (SNOTEL data; water year 1981–2010); Western Regional Climate Center (1981–2010 normal for Boulder and 1971–2000 normal for Longmont, which was discontinued in 2005).

Boulder County temperature records show long-term upward trends. However, no study has been done to conclusively link these local observations to anthropogenic (human-caused) climate change. Local observations tend to have larger natural variations than regional averages, and these large variations can mask an underlying trend. In order to gain some confidence in the trends and their causes, climatologists consider studies of larger relevant regions. In the most relevant of these studies for Boulder County, the large-scale pattern of warming, earlier snowmelt, and earlier streamflow in mountainous areas of the western United States has been attributed, at least in part, to human-caused GHG emissions. This was done by showing that the observed regional trends were both consistent with the response to increasing GHGs, and inconsistent with purely natural variability (Bonfils et al., 2008).

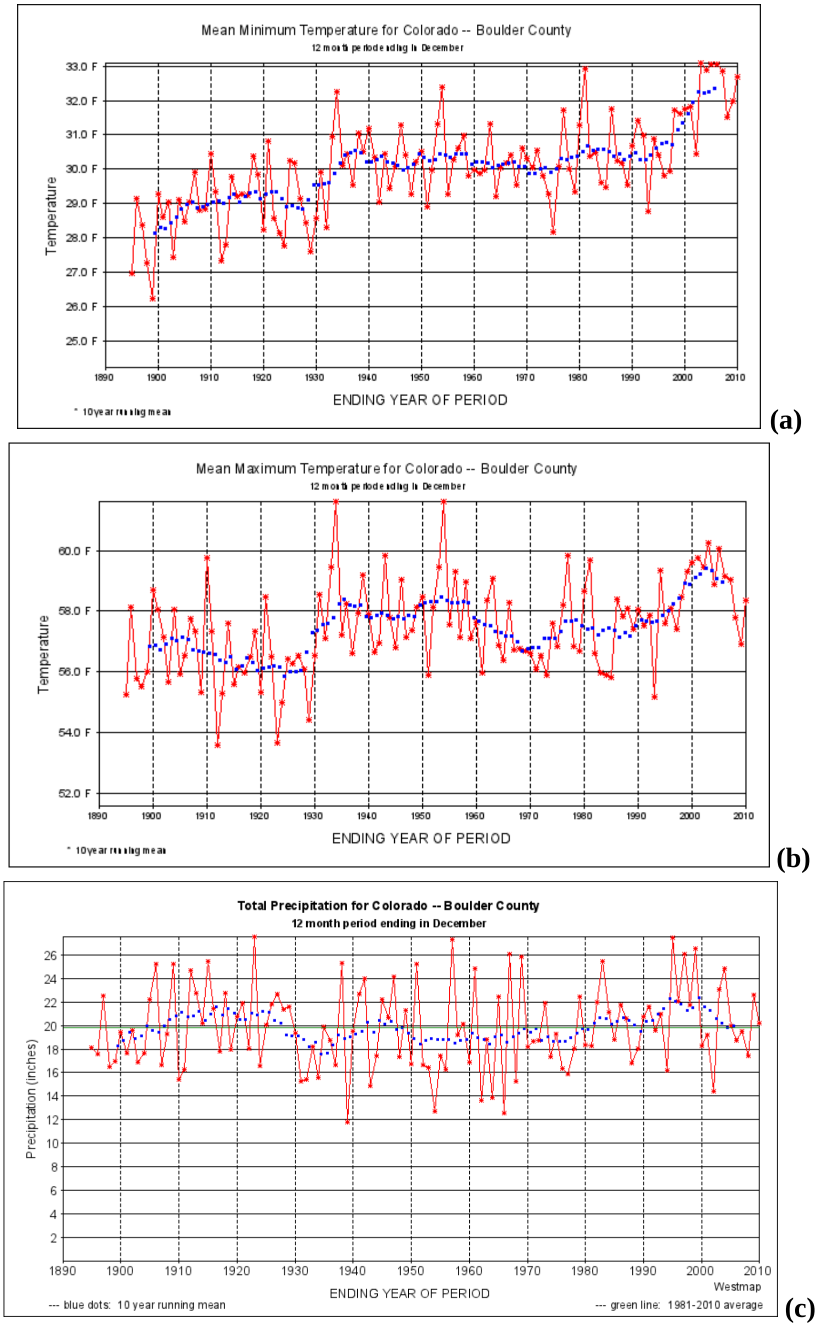

Figure 2.2. Average Boulder County climate 1890–2010. The annual mean of the (a) daily minimum temperature, (b) daily maximum temperature, and (c) total annual precipitation for the area average over all of Boulder County. The 10-year moving average is shown in blue.

Source: Western Regional Climate Center (http://cefa.dri.edu/Westmap/Westmap_home.php) using PRISM data.

2.3 The Future of Boulder County's Climate

Under a scenario of high global GHG emissions, the results from several different climate models (GCMs) project average temperature in the region including Boulder County to increase around 1.5–4°F by 2025, 2.5–5.5°F by 2050, and 6–11°F by 2090 (see Table 2.1, rounding to the nearest 0.5 degrees). These changes are measured relative to a baseline period of 1950–1999. There is high confidence in warming on a regional scale. Average daily maximum and daily minimum temperatures also are projected to increase, with summer daily maximum temperature warming the most in these models.

Table 2.1. Projected annual temperature change (°F) for three GHG emissions scenarios at three different time periods in the future. For each case we show the range of climate model projections which is depicted by the 10th (low), 50th (middle), and 90th (high) percentiles of the results from an ensemble of 16 different climate models.

	Low emissions (B1)			**Medium emissions (A1B)**			**High emissions (A2)**		
	10th	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
2020–2040	1.5	2.8	3.5	1.5	2.9	4	1.6	2.7	3.9
2040–2060	1.7	3.5	4.5	2.8	4.9	6	2.4	4.8	5.5
2080–2100	2.9	4.8	6.9	4.3	7	9.6	5.8	8.7	11.1

The climate models, on average, show little change in annual total precipitation. There is less confidence in how annual precipitation may change, mainly because some climate models show an increase while others show a decrease in our region (see Table 2.2). However, climate models tend to agree on an increase in precipitation in winter and a decrease in the spring. There is less confidence in how the total summer precipitation may change, with little agreement among the GCMs and known difficulties in simulating summer thunderstorms. However, the higher-resolution regional climate models (RCMs) investigated here show significantly drier summers in the future, a possibility that should not be discounted. In general, heavy and extreme precipitation (e.g., the magnitude of the 100-year event) have the potential to increase in a warmer climate. RCMs consistently show heavy precipitation events increasing during winter and spring months. However the projections for heavy summertime precipitation in Boulder County is more complicated and would benefit from further research.

Table 2.2. Projected annual precipitation change (%) for three GHG emissions scenarios at three different time periods in the future. For each emissions scenario and time period we show the range of climate model projections which is depicted by the 10th (low), 50th (middle), and 90th (high) percentiles of the results from an ensemble of 16 different climate models.

	Low emissions (B1)			Medium emissions (A1B)			High emissions (A2)		
	10th	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
2020–2040	-6.9	-0.2	8.8	-6.8	-0.7	5.4	-7.1	-0.7	5.7
2040–2060	-6.7	2.9	6.7	-10.8	0.7	5.7	-11.3	0.0	6.9
2080–2100	-6.3	1.3	13.6	-13.8	0.7	10.6	-18.5	-1.6	15.0

The hydrologic consequences of warming are understood with more confidence – a greater fraction of precipitation falling as rain rather than snow, earlier peak snowpack, earlier snowmelt and peak runoff, greater water demand by natural vegetation. The effect of climate change on the total volume of natural flows (flows that would occur in the absence of diversion and storage) depends on a balance between precipitation and losses from evaporation, sublimation, and water use by natural vegetation. While current hydrologic modeling efforts suggest a reduction in total natural streamflow on average, there is considerable uncertainty in these projections with both decreases and increases in flow possible. Increase in water demand for residential and agricultural irrigation due to a longer growing season and warmer temperatures may decrease overall water availability regardless of changes in natural flow.

In order to present results relevant to Boulder County, this report uses data in which climate model results have been translated to a much smaller spatial scale through a technique known as downscaling (see Figure 2.3 for the gridboxes from both datasets used in this study). Results shown here are based on two widely available downscaled datasets with different strengths. Both of these datasets contains the results from several different climate models. The first dataset is the "Bias Corrected and Downscaled WCRP CMIP3 Climate and Hydrology Projections," which uses a statistical downscaling technique called bias-corrected spatial disaggregation (BCSD; Maurer et al., 2007). The BCSD dataset includes a range of projections that have been downscaled from 16 GCMs. This dataset was chosen because it provides a broad sampling of available GCM projections to estimate the range of possible future climates. The BCSD data include monthly projections through the year 2100. The spatial patterns of how temperature and precipitation change in the BCSD data are taken almost directly from GCMs.

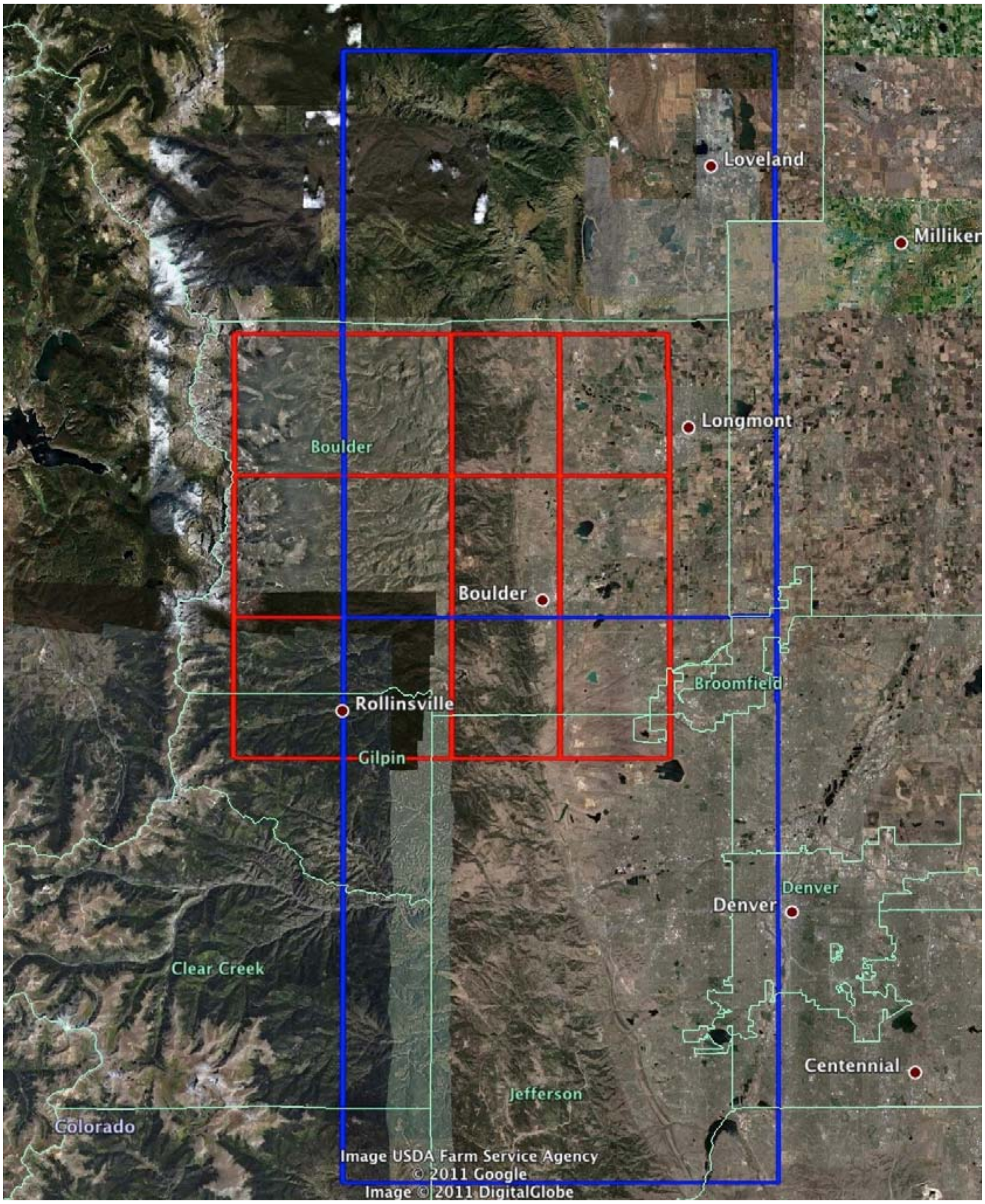

Figure 2.3. Grid boxes from the BCSD and North American Regional Climate Change Assessment Program (NARCCAP) datasets used for this analysis. The red grid boxes represent the spatial coverage of twelve 1/8th degree (approximately 12 km) BCSD grid cells used in this analysis. The blue grid boxes represent the spatial coverage of two 50 km NARCCAP grid cells used in this analysis.

The second dataset is the NARCCAP RCM ensemble (Mearns et al., 2009). The NARCCAP ensemble includes RCMs that are used to downscale the results from four GCMs. It was chosen because it provides a more detailed representation of physical processes at finer spatial resolution than the GCMs. However, NARCCAP projections are only available for the period 2040–2070. NARCCAP models use 30-mile (50-km) grid cells, allowing them to resolve the topography of the Front Range more accurately than the global models do with their 120- to 240-mile (200- to 300-km) grids. In particular, the transition from the Great Plains to the Rocky Mountains is much more abrupt (more closely resembling the actual change in topography) in the NARCCAP regional models. Nonetheless, the area of a NARCCAP grid cell is still slightly larger than Boulder County, so the regional models do not capture topographical differences within Boulder County.

Both the BCSD and NARCCAP datasets provide useful information for the detailed analysis that follows. For example, the NARCCAP dataset gives us access to daily minimum and maximum temperature as simulated by the models, whereas the BCSD dataset only contains daily average temperature. The NARCCAP dataset also contains daily precipitation model output, enabling an analysis of how heavy precipitation events may change. For all of the analyses below, we focus on the A2 emissions scenario, which is a storyline that provides plausible future population growth and socioeconomic development. The A2 scenario results in relatively high GHG emissions compared to other scenarios (e.g., B1 and A1B), but with the advantage of emissions data since the scenarios were developed in 2000, actual emissions over the past 10 years are consistent with the A2 scenario.

2.3.1 Average temperature

Under a scenario of high global GHG emissions (the A2 emissions scenario), the 16 models in the BCSD dataset project temperature to increase by around 1.5–4°F by 2030, 2.5–5.5°F by 2050, and 6–11°F by 2090. The median increase among the models is 2.7°F by 2030, 4.8°F by 2050, and 8.5°F by 2090 (see Table 2.1). Figure 2.4 shows the monthly values of recent (1950–1999) and projected climate for three periods in the future centered on the years 2030, 2050, and 2090. The results from each of the 16 downscaled GCMs is shown. All of these models project warming, some more than others, but note that the projected warming is somewhat greater in summer than in winter.

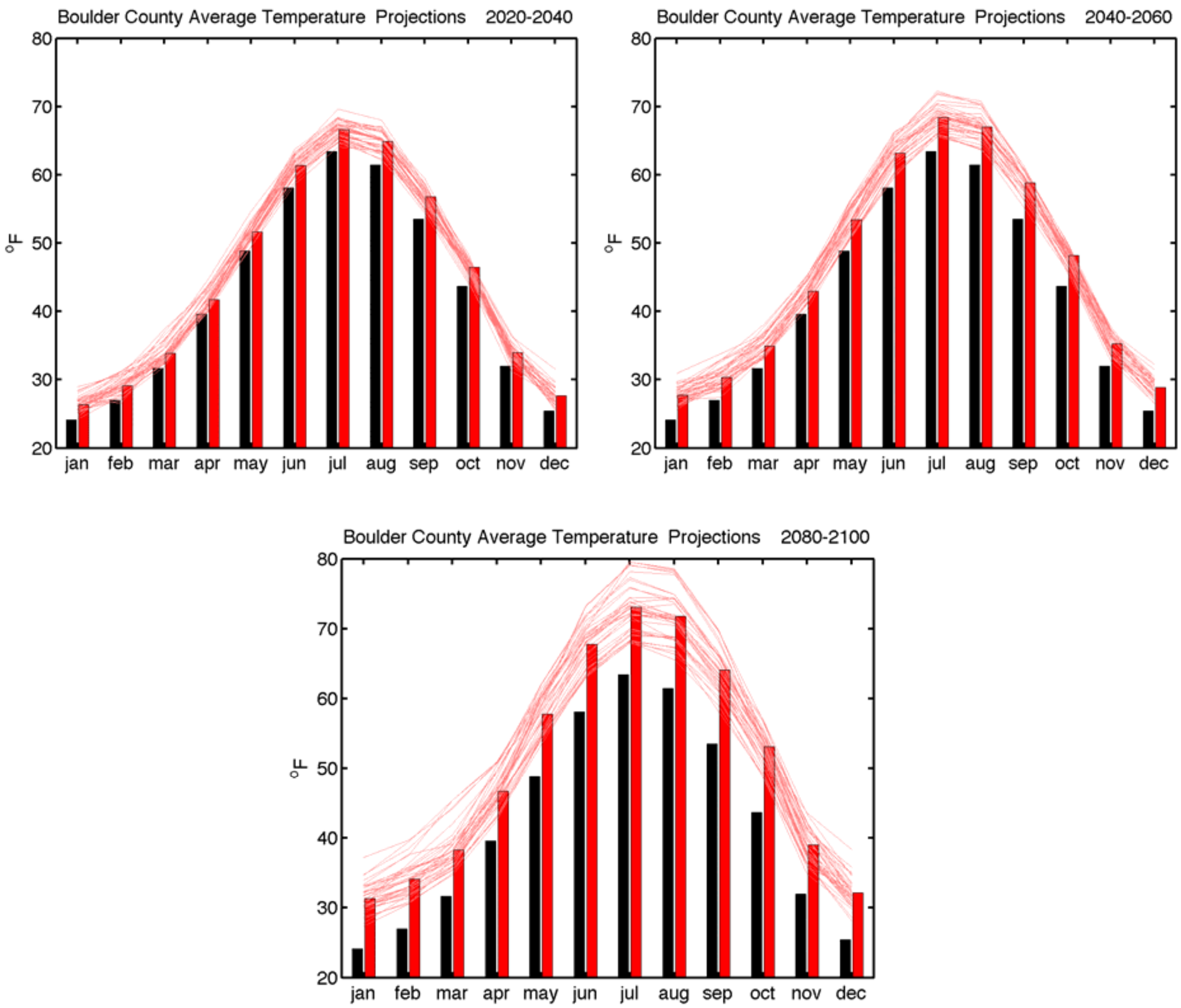

Figure 2.4. Historical and projected monthly mean temperature (°F) for Boulder County under the high (A2) emissions scenario for the periods 2020–2040, 2040–2060, and 2080–2100. The historical average for 1950–1999 (black bars), the mean projections from 16 climate models (red bars), and the projections from the individual model (red lines) are shown. The greatest warming is in summer.

Source: LLNL, 2011. Analyzed and ploted by J. Barsugli.

Table 2.1 shows the range of future temperature changes under low, medium, and high emissions scenarios for the 16 model in the BCSD dataset. The range of possibilities is indicated by the 10th and 90th percentiles of the 16 models considered in the BCSD dataset. This range should only be considered approximate, as many sources of uncertainty are not considered in the climate models.

Figure 2.5 shows results from NARCCAP models of temperature changes by season. These results tell a similar story to the BCSD results with regard to temperature change, though they show a smaller range because of the smaller number of climate models used in the NARCCAP data.

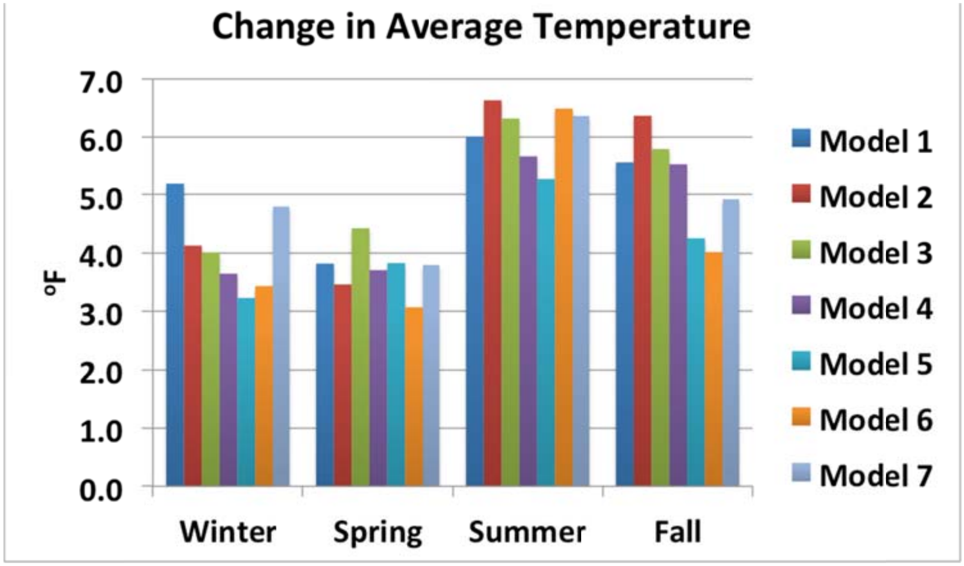

Figure 2.5. Projected change in average temperature (°F) by season for an area that includes Boulder County from seven RCM simulations[2] available from the NARCCAP program. The change under the high GHG emissions scenario (A2) between the periods 1970–1999 and 2040–2069 is shown. Models 1–7 for all NARCCAP results are defined in footnote 3.

Source: Based on NARCCAP (http://narccap.ucar.edu) data. Analysis by Imtiaz Rangwala, University Corporation for Atmospheric Research (UCAR) Pace postdoctoral fellow.

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2. Each simulation uses an RCM to downscale from a global climate model. The regional model is listed first, then the global model. 1. Canadian RCM (CRCM) + Canadian GCM (CGCM3) 2. Hadley Centre Regional Model (HRM3) + Hadley Centre Climate Model (HADCM3) 3. Regional Climate Model 3 (RCM3) + CGCM3 4. Weather Research and Forecasting Model (WRFG) + National Center for Atmospheric Research (NCAR) Community Climate System Model (CCSM) 5. MM5 mesoscale model (MM5I) + CCSM 6. RCM3 + Geophysical Fluid Dynamics Climate Model (GFDL) 7. CRCM + CCSM. More information on these models is available from http://narccap.ucar.edu. Only the first four had data available separately for Tmin and Tmax at the time of this report. The model data were first put onto a common 0.5 degree (~ 50 km) grid in latitude and longitude using cubic spline interpolation, and two of these grids that overlapped Boulder County were averaged.

2.3.2 Maximum daily temperatures

Projected changes in maximum daily temperatures from four RCM simulations in the NARCCAP program are shown in Figure 2.6. These projections are for the period 2041–2070. Daily maximum temperatures are expected to rise more than the minimum temperature during the summer and fall, raising the possibility of increased intensity of heat waves. For example, the maximum temperatures increase by approximately 4°F in the winter and by approximately 7°F in the summer in these four models.

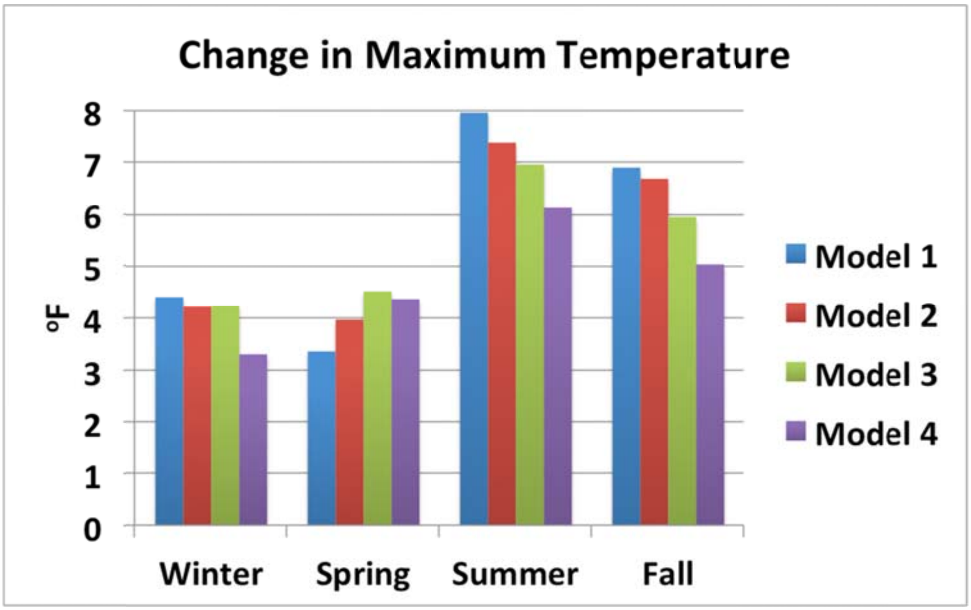

Figure 2.6. Change in maximum daily temperature (°F) by season from four RCM simulations in the NARCCAP program. The change under the high (A2) GHG emissions scenario between the periods 1970–1999 and 2040–2069 is shown. See footnote 3 to identify each model.

Source: Based on NARCCAP (http://narccap.ucar.edu) data. Analysis by Imtiaz Rangwala, UCAR Pace postdoctoral fellow.

2.3.3 Minimum daily temperatures

Changes in minimum daily temperatures from four RCM simulations in the NARCCAP program are shown in Figure 2.7. Seasonal differences are less pronounced than for maximum temperatures.

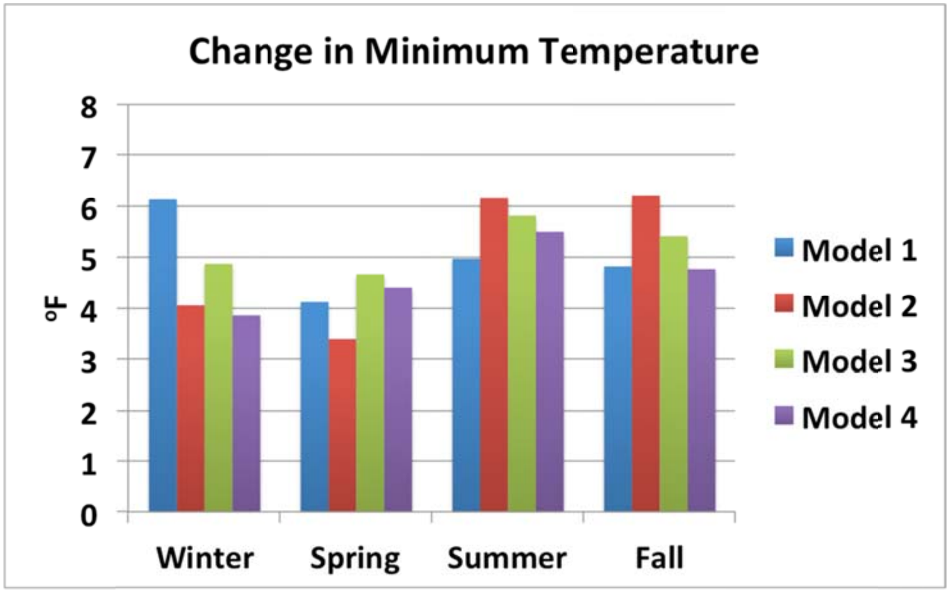

Figure 2.7. Change in minimum daily temperature (°F) by season from four RCM simulations in the NARCCAP program. The change under the high (A2) GHG emissions scenario between the periods 1970–1999 and 2040–2069 is shown. See footnote 3 to identify each model.

Source: Based on NARCCAP (http://narccap.ucar.edu) data. Analysis by Imtiaz Rangwala, UCAR Pace postdoctoral fellow.

2.3.4 Extreme heat

As the average summer temperatures increase, so does the likelihood of increased high temperatures. Presently, Boulder County experiences very few days with a maximum temperature above 100°F during an average summer. However, one analysis of increasing extreme temperatures indicates that the number of days above 100°F will increase to more than 10 per year under a lower emissions scenario and between 20 and 30 under the high (A2) emissions scenario (USGCRP, 2009). Because heat waves are typically a direct consequence of large-scale warming, projected increases in temperature give high confidence in the likelihood that heat waves, by this definition, will increase. However, increasing nighttime minimum temperatures can have a large effect on the consequences of heat waves for human health, as can increases in atmospheric humidity. While the temperature trends shown in Figures 2.6 and 2.7 can give general indications, a more detailed analysis of heat indices in the RCMs, or from other downscaling methods, would shed more light on this important topic.

2.3.5 Extreme cold

Boulder County experiences occasional extreme cold air temperatures in winter due to “cold air outbreaks” that occur when a cold air mass moves in from the north. In a warmer climate it might be expected that winters will have fewer severe cold events, but this is not necessarily the case. There is only one study on this topic that includes the western United States, but it indicates that although cold snaps are projected to decrease by 50–100% across most of the northern hemisphere, the western United States might be an exception. Most of the climate models analyzed in that study showed a slight decrease in the number of cold snaps, although in two cases the models showed an increase. The persistence of these events into the future was attributed to changing wind patterns in the models that allowed for more cold air to move southward (Vavrus et al., 2006).[3]

2.3.6 Frosts and freezes

Warmer temperatures generally translate into an increase in growing-degree-days (GDDs) and a longer growing season. However, a combination of an earlier start to the growing season might leave plants more vulnerable to late frosts (USGCRP, 2009). Indeed, increasing frost damage has been reported in a study at the Rocky Mountain Biological Laboratory near Crested Butte, Colorado (Inouye, 2008).

2.3.7 Snowmelt and runoff timing

Higher temperatures can lead to declining snowpacks and earlier snowmelt and runoff. If Boulder County’s future climate warms as expected, snowpack would become a less reliable mechanism for water storage, even without any changes in total precipitation.

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3. A cold air outbreak in this study is defined as “ an occurrence of two or more consecutive days during which the local mean daily surface air temperature is at least two standard deviations below the local wintertime mean temperature” in the climate model. To be consistent, both past and future cold outbreaks are defined relative to the same historical (late 20th century) climatological averages. Based on the 1981–2010 climate normals for January at the Boulder COOP observing station, this definition would imply a 24°F departure below normal, or a daily average temperature below -5°F, lasting for two days or more.

A recent study of the City of Boulder's water supply system under climate change simulated the change in natural streamflow for Boulder Creek at Orodell (2 miles upstream from the mouth of Boulder Canyon). This study used a hydrology model under several idealized scenarios of temperature and precipitation change. It was found that an increase of 5.4°F in average temperature resulted in a 4% decline in annual streamflow. A scenario with no temperature change but a 20% annual decline in precipitation resulted in a 13% decline in streamflow, with streamflow and runoff peaks shifting from June to May (Smith et al., 2009).

2.3.8 Precipitation and seasonal shifts

Precipitation changes are more variable from model to model, but the average across all models indicates the possibility of a seasonal shift in precipitation – an increase in precipitation from December through March and a decrease during April and May. In particular, there is substantial, but not unanimous, model agreement on a modest increase in the winter precipitation. This seasonal shift becomes more pronounced as the overall climate changes throughout the century. There is no clear signal of a shift in total annual precipitation.

Figure 2.8 shows BCSD-projected changes in precipitation by month, demonstrating both the relatively high uncertainty in projections of precipitation and the shift from spring to more winter precipitation. Figure 2.9 shows NARCCAP projections of seasonal precipitation changes. Like the BCSD results, the NARCCAP models show an increase in winter precipitation. However, the most striking difference from the BCSD results is that almost all the NARCCAP regional models project a decrease in summer and fall precipitation. These differences in summer can be ascribed to the different ways in which the RCMs compute the rain from thunderstorms and other convective storms as well as other differences in model formulation.

2.3.9 Extreme and heavy precipitation and flooding

Heavy precipitation events that lead to flooding occur at the short-term time scales of weather, rather than the multi-year time scales of climate. The global and RCMs used to make climate projections simulate the day-to-day weather of the present and the future, allowing us to examine how heavy precipitation events might change in the future. However, extreme events are, by their very nature, uncommon. Quantifying trends at a given location is quite difficult, and no trends in the historic record of extreme climate events have been definitively detected in Boulder County. To get a projection of how extremes might change, we make inferences from general scientific principles and from model results. Although these represent plausible future trends, the general level of scientific confidence varies. In general, the impacts on hydrology that follow from increasing temperature are considered more reliable than those from changes in precipitation. Projected changes in extremes should also be interpreted with caution.

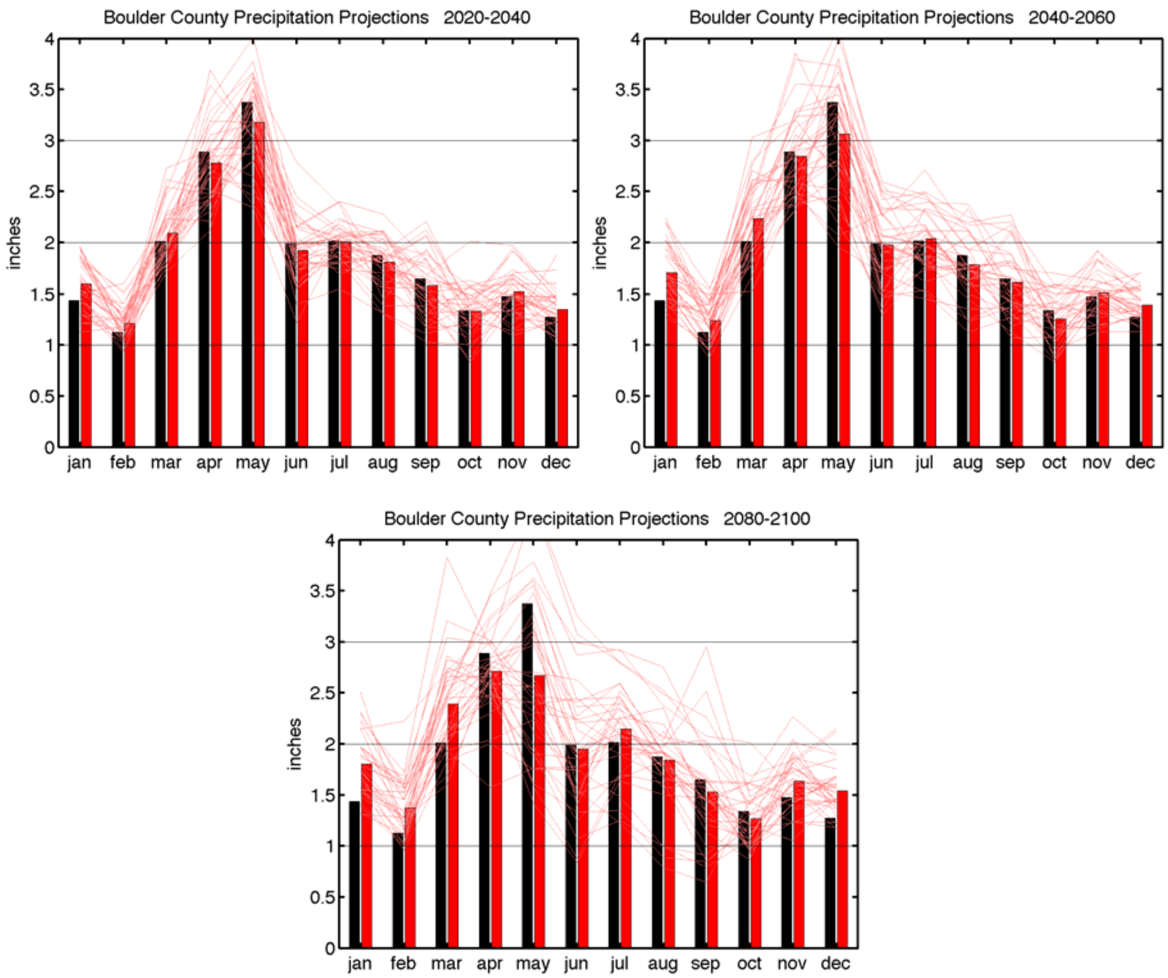

Figure 2.8. Historical and projected monthly precipitation (inches) for Boulder County under the high (A2) emissions scenario for the periods 2020–2040, 2040–2060, and 2080–2100. The historical average for 1950–1999 (black bars), the mean projections from 16 climate models (red bars), and the projections from the individual model simulations (red lines) are shown. Modeled precipitation shows an increase in winter and a decrease in spring.

Source: LLNL, 2011. Analyzed and ploted by J. Barsugli.

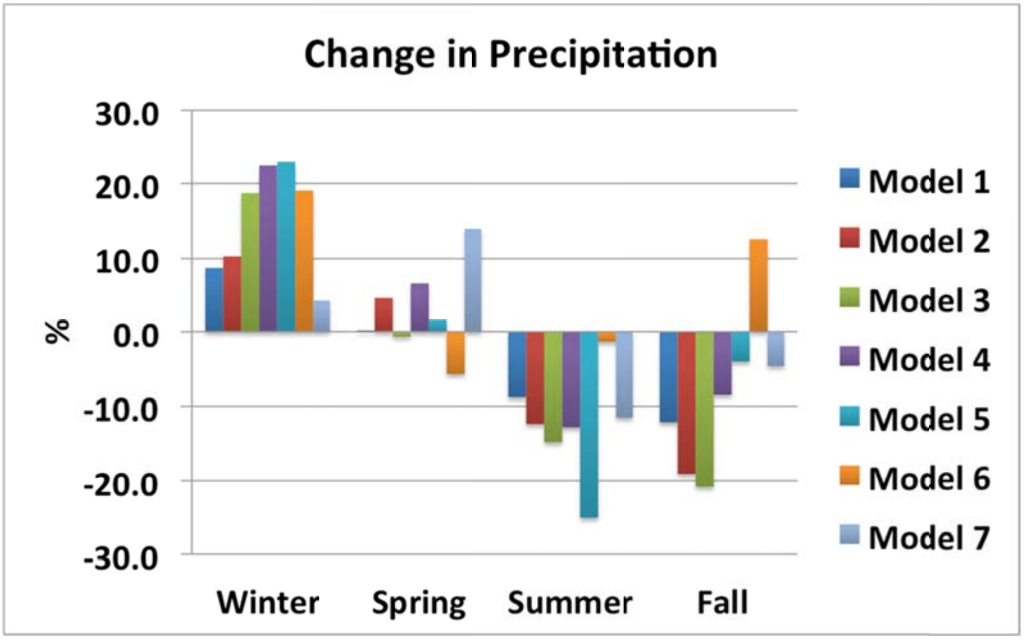

Figure 2.9. Percent change in precipitation by season from seven RCM simulations in the NARCCAP program. The change under the A2 (high) emissions scenario between the 1970–1999 average and the 2040–2069 average is shown for the grid cells that overlap Boulder County. See footnote 3 to identify each model.

Source: Based on NARCCAP (http://narccap.ucar.edu) data. Analysis by Imtiaz Rangwala, UCAR Pace postdoctoral fellow.

Globally, precipitation extremes and their hydrological impacts (e.g., the magnitude of 100-year floods) are expected to get larger because in most places, higher temperatures will result in increased atmospheric water vapor available to form precipitation (Bates et al., 2008). The projected climate becomes more favorable to the formation of severe storms over both the northern and southern Great Plains (Trapp et al., 2009). The situation is more complex in Colorado, where many models show an increase in total winter precipitation, but a marked decrease in total precipitation during spring or summer. The latter seasons are when Boulder County can get large convective rain events. However, climate models clearly show that precipitation extremes can become larger even in areas experiencing unchanged or decreasing total precipitation. In that circumstance, rainy days would become less frequent, but if conditions are right for an extreme event, and more moisture is available in the atmosphere, then larger extreme events are possible.

Are there indications that this can happen in Boulder County? Figure 2.10 shows results from an ongoing study of daily precipitation in the NARCCAP RCMs for a region that includes the Front Range and adjacent plains. The event studied has a return period of about two years – that is, one such event would occur typically every two years during the months in question. Most of the models show increases in these heavy events in the winter and spring months (only January – February is shown). In summer, the pronounced drying seen in the total precipitation overwhelms the tendency for heavy precipitation events to increase. However two models do show increases in these heavy events despite declines in total precipitation. The results shown here do not rule out the possibility that events with even longer return periods could increase in magnitude.

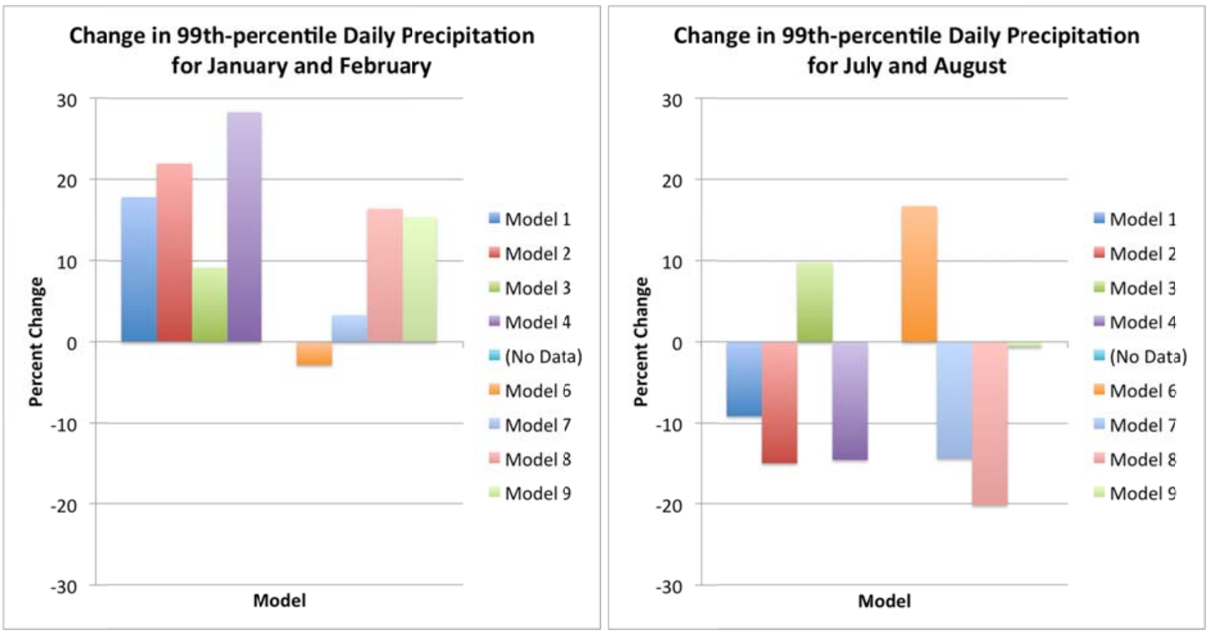

Figure 2.10. Heavy precipitation on the Front Range increases in January and February (left) in all but one of the NARCCAP RCMs.[4] For July and August two models show substantial increases while most of the others show substantial declines. The 99th percentile of daily precipitation for each two-month period corresponds to an event with an approximately two-year return period. See footnote 3 to identify each model.

Source: Based on NARCCAP (http://narccap.ucar.edu) data. Analysis by J. Scott, National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL).

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4. Model identifiers are the same as in Figure 3. Model 5 was not available for this analysis. Additional NARCCAP models are shown: Model 8, WRFG + CCSM; Model 9, Timeslice + GFDL. Models are described at http://narccap.ucar.edu. The spatial domain included a 100 km × 300 km area that includes the Front Range and neighboring plains.

It should be noted that the grid cells in both the GCMs and regional models are much too large to directly simulate thunderstorms. Instead they calculate the thunderstorm rainfall from parameters such as the amount of moisture converging into a region. However a new class of models can directly simulate thunderstorms and is being used to investigate heavy and extreme events under climate change. An ongoing study is applying a 0.8 mile resolution weather model to study heavy and extreme events under present-day and projected future climate conditions. This study focuses on events with three-year and longer return periods for the entire Front Range. The findings project an increase in the maximum precipitation that can fall at any one location for these events. A warmer climate can also affect the type of precipitation that falls, and this can have an impact on flooding. The heavier precipitation is accompanied by a greatly reduced amount of hail reaching the ground at high elevations. Because hail is thought to slow runoff because it takes time to melt, the result implies an increase in high-elevation flooding risk (Mahoney et al., In press). However, the results of this study should be interpreted with caution until a greater range of climate change scenarios can be investigated.

2.3.10 Springtime storms

The City of Boulder typically gets the greatest total precipitation in the months of April and May, with large amounts in the rest of Boulder County as well in those months. What do the climate models say about the future of these springtime storms? Climate scientists have confidence that wintertime storms are well simulated by the global models. However, the springtime storms in Boulder County often involve more complicated atmospheric motions, including a significant upslope component that draws on moisture from the Great Plains. The main indication we have for decreased springtime storms is the decrease in the average precipitation projected by climate models for April and May. More detailed analysis of the next generation of global and RCM output could clarify the extent to which these storms are accurately modeled and how they are projected to change.

2.3.11 Drought

The City of Boulder Drought Plan (2004) identifies one-year severe droughts and extended droughts as areas of concern. Meteorological drought is defined as an extended period of low precipitation. There is, however, considerable uncertainty regarding projections of the annual total precipitation for Boulder County. However a declaration of drought by a municipality can involve a consideration of other factors influencing water supply, including snowpack, runoff efficiency (the amount of precipitation that makes it into the streams), and storage. Many of these factors are directly or indirectly affected by temperature. Warmer temperatures can lead to more severe drought impacts, even if the precipitation deficit is the same. In addition, the projected seasonal shift in precipitation and earlier runoff could see additional stress on natural and human systems in the summers of drought years. These seasonal impacts could become particularly acute under the scenario of large reductions in summer precipitation seen in the RCM simulations. The increasing role of temperature in creating drought suggests that precipitation monitoring alone will not be sufficient. Instead increased long-term monitoring of soil moisture and other drought indicators would be prudent.

2.4 Impacts on Water Supply

There has been much research on the implications of increasing temperature on the hydrologic cycle (Bates et al., 2008; USGCRP, 2009). Multiple studies have investigated recent trends in temperature-related impacts on hydrologic trends (Stewart et al., 2005; Mote et al., 2005) and attributed the west-wide pattern of these trends to anthropogenic climate change (Pierce et al., 2008; Das et al., 2009; Hidalgo et al., 2009). Hydrologic impacts include a greater percentage of precipitation falling as rain, advances in streamflow timing and peak runoff, and declines in snowpack.

Broad west-wide average trends are expected to continue into the future in Boulder County as the climate warms. First, a greater percentage of precipitation is projected to fall as rain rather than snow. This is particularly true in spring and fall when temperatures are closer to the freezing point and a small warming can have a large impact. Under more severe warming scenarios, this effect could lead to more rain events in mid-winter. Second, higher temperatures can lead to declining spring snowpack and earlier snowmelt and runoff. The temperature-driven trend to decreasing snowpack could be somewhat offset by the projected increase in wintertime precipitation. If there were warming with no change in the total precipitation, snowpack would become a less reliable mechanism for water storage. If the climate shifts to a more rain-dominated regime, then the predictability of water supply based on, for example, April 1 snow-water equivalent (SWE) is reduced. Warmer temperatures, along with a longer growing season, lead to greater evapotranspiration from the natural landscape that can result in a reduction in runoff and annual streamflow. However, the generally high elevation and cold snowpack of Colorado can, to some extent, delay the impacts of a warmer climate, compared to what is projected to happen in mountain ranges at lower elevations.

Precipitation also has a strong influence on total runoff and streamflow. The uncertainty in how precipitation might change, as discussed above, is an important factor in evaluating the confidence in hydrologic projections. However, there is some indication that an increase in winter precipitation can offset some of the decline in runoff due to increased evapotranspiration from a longer snow-free growing season.

East Slope water supplies in Boulder County: Two recent studies have investigated the sensitivity of the hydrology of Boulder County watersheds to changes in temperature and precipitation. Given an understanding of how runoff responds individually to changes in temperature and precipitation, it is possible to estimate how an individual basin will respond to a changed climate. As mentioned earlier, the City of Boulder's climate vulnerability study found that a 5.4°F (3°C) warming resulted in a 4% decline in annual streamflow for Boulder Creek at Orodell, near the mouth of Boulder Canyon. A scenario with no temperature change, but a 20% annual decline in precipitation, resulted in a 13% decline in streamflow. Streamflow and runoff peaks shift from June to May (Smith et al., 2009).

The Joint Front Range Climate Change Vulnerability Study, an effort of a number of Front Range communities including Boulder and Longmont, is investigating the response of Front Range watersheds including the South Platte River, St. Vrain Creek, Boulder Creek, and the Cache La Poudre River to climate change. This study uses two hydrologic models, the WEAP model (from the Stockholm Environmental Institute) and Sacramento model (developed by the National Weather Service). Preliminary results from this study show that a 1.8°F (1°C) warming, with no change in precipitation, would result in a 4–5% decrease in streamflow in both Boulder and St. Vrain creeks and a 7.2°F (4°C) increase would yield a 16–21% decrease in flow. These models show considerably more sensitivity to temperature change than the City of Boulder study above. This difference illustrates that additional uncertainty is introduced by the process of hydrologic modeling. Although the hydrologic models generally agree on the shift in timing of the flows due to warmer temperatures, the overall loss from the basin due to evapotranspiration is harder to model and typically shows greater differences from model to model.

In addition, further information about the possible impacts of climate change on streamflow in Boulder County is coming from emerging science of using very high-resolution weather models to simulate the climate of the future. This new research is exemplified by the Colorado Headwaters project at the National Center for Atmospheric Research (NCAR; Rasmussen et al., 2011). An initial effort has modeled the snow accumulation season (November through April) with 6-km (3.6 mile) resolution over a limited spatial domain that includes the Colorado Rockies. Results were shown for Boulder Creek, including a 12% increase in precipitation, a 28% increase in November – April runoff, a 9% reduction in maximum SWE, and a date of maximum SWE occurring 16 days earlier. This work suggests that the climate models have understated the potential for increased precipitation in winter. However, several methodological issues noted in that paper make it difficult to directly compare this result to the other studies cited above.

Colorado River water supplies: Many Boulder County municipalities receive water from the Colorado River Basin through the Windy Gap and Colorado – Big Thompson projects. The City of Boulder Drought Plan (2004) found that there is a high correlation between droughts in the Front Range watersheds and the Colorado River headwaters. Table 2.3 presents a short summary of studies on the effects that climate change could have on the hydrology of the Colorado River basin. These studies indicate a 6–20% decline in annual runoff for the Upper Colorado basin.

Table 2.3. Studies of upper Colorado River basin natural streamflow under climate change

Study	Temperature	Precipitation	Annual streamflow	Time period
Christensen et al. (2004)	+3.1°F	-6%	-18%[a]	2040–2069
Milly et al. (2005)	Not shown	Not shown	-10 to -20%	2041–2060
Christensen and Lettenmaier (2006)	+4.5°F	-1%	-6%[a]	2040–2069
Colorado Water Conservation Board (2010)	+3.6°F	-1.5%	-7%[a]	2040
U.S. Bureau of Reclamation (2011)	+3.8°F	-0.3%	-9%[a]	2050

a. The mean or median result of these studies is reported here. These studies investigated many climate projections and show a range of results including both increases and decreases in annual streamflow.

The NCAR Colorado Headwaters study mentioned above also showed changes in the Upper Colorado River basin. In particular, the researchers found a larger increase in winter precipitation compared to GCM projections – about 10–15% greater for the headwaters.

Finally, it should be noted that a number of factors besides increases in temperature affect rates of snowmelt and runoff. Known and suspected factors include airborne dust from the Colorado Plateau, tree mortality from bark beetle infestations, and unusual patterns of snow accumulation and springtime temperatures. Ongoing research is aimed at understanding the various influences of these factors, which could be rather significant. One study found that typical amounts of dust in recent years had reduced overall flow in the Colorado River by 5% compared to pre-development dust amounts. The reduction in flow in the models was due to more snow-free ground in spring, more evaporation, a longer growing season, and increasing water use by vegetation (Painter et al., 2010). Although warmer temperatures are very likely to result in earlier snowmelt and runoff, it is important to remember that these other factors, which are not necessarily tied to climate change, might be responsible for some portion of recent trends in snowmelt timing.

Uncertainty in hydrologic projections

All the studies mentioned above show that increased temperatures lead to increased losses from evapotranspiration. The long-term yield of a basin is largely determined as the difference between the total precipitation and losses through evapotranspiration and sublimation. These studies underscore how our uncertainty about future precipitation informs projections of hydrologic yield. It is probably best to draw from the advantages each study has to offer. The studies listed in Table 2.3 were able to investigate a large range of future climate scenarios and indicate that in most of these the increased losses from evapotranspiration leads to decreased annual runoff and streamflow. However, the new results from the Colorado Headwaters project indicate that increased wintertime precipitation might play a larger role in offsetting these losses.

By comparing many studies using different models and methodologies, it is possible to gain a better understanding of the various sources of uncertainty in the projections. All the above studies except the Colorado Headwaters study were able to investigate a large range of future climate scenarios and many of these show decreased runoff in the future.

2.5 Impacts on Emergency Management

Wildfires: Although there are no studies on wildfires in Boulder County in particular, there is good evidence that wildfires across the western United States have been increasing and will likely continue to increase in the future. A 2006 study found a fourfold increase in the number of wildfires since 1986 compared to the 1970–1986 period, with a sixfold increase in burned acreage. Those results were attributed to a 78-day increase in active wildfire season and a fivefold increase in average fire duration. Much of that, in turn, can be attributed to earlier snowmelt and hotter summertime temperatures (Westerling et al., 2006). Tree-ring records of fire scars and debris found in alluvial fans show that warmer and drier periods are associated with more frequent and severe wildfires (CCSP, 2008). Given that climate projections indicate continued advance in snowmelt timing and increasing summer temperatures, wildfire conditions across the West are likely to worsen in the future.

Storms and flooding: As mentioned earlier, GCMs and our understanding of the climate system indicate that precipitation extremes (e.g., 100-year floods) are likely to get larger. The situation is more complex in Colorado, where some models show a marked decrease in average summer precipitation, the season when we typically get our largest daily precipitation events. However, even if precipitation overall decreases and rainy days become less frequent, larger extreme events result from added moisture in the atmosphere. This is bolstered by the results of a preliminary high-resolution study that projects an increase in precipitation for extreme events, accompanied by greatly reduced incidences of hail reaching the ground and more extreme precipitation at high elevations (above 8,200 feet) falling as rain (Mahoney et al., Forthcoming). Although these factors would generally imply a potential increase in flash flood frequency, some studies have found that reduced spring snowpack could actually result in lower flood frequency in the Interior West (CCSP, 2008). No specific studies have been done for Boulder County, however, where local factors such as the character of canyons might affect flood frequency and severity.

Finally, Boulder County currently experiences a number of damaging windstorms each year, especially from Chinook winds. However, no current analyses are available to provide specific evidence for changes in the frequency or intensity of these events.

2.6 Impacts on Human Health

Extreme temperatures: Among the clearest signals from the existing climate change research is the projected warming in the county over time. As described above, this is expected to result in an increase in average temperatures, daily minimum and maximum temperatures, and the number of days exceeding 100°F. As an example of current conditions, temperature data for Boulder from the NOAA ESRL/Physical Sciences Division (PSD) show that there were 8 days between January 1, 2000 and November 1, 2011 where the maximum daily temperature was or exceeded 100°F. In this same timeframe, there were 88 days where the temperature exceeded 95°F. These data are presented as a rough baseline of the number of high temperature days the City of Boulder currently experiences. Cold outbreaks in the winter are expected to continue, even though overall average temperatures are expected to rise. What this means for human health is the number of extreme temperature days (extreme heat or cold) is anticipated to increase from current conditions (increase in occurrences of extreme heat days, maintain frequency of extreme cold days).

Air quality: Several aspects of climate change have the potential to degrade air quality and thus human health. First, seasonal increase in temperature could contribute to a longer ozone season, as ozone is formed when nitrous oxides (NOx) and volatile organic compounds (VOCs) mix in the presence of sunlight. Second, longer and hotter summer days could increase the demand for electricity for air conditioning – the increased power demand will, all else equal, increase power plant emissions of NOx and possibly particulate matter. The exact impact of climate change impacts on air quality as a result of increased summertime power demand are uncertain and will be sensitive to how the increased demand is met, in terms of the location and type of generating sources used. Third, as noted in Section 2.5, climate change could result in more wildfires in the Front Range region, including Boulder County. Smoke and particulate matter from wildfires degrade air quality and have the potential to create dangerous conditions, especially for those with respiratory illnesses such as asthma or chronic bronchitis. Finally, research suggests climate change could contribute to increased abundance of some airborne pollens, such as ragweed, a common allergen (Ebi et al., 2008).

Water quantity and quality: It is likely the county will see an increase in precipitation associated with large-scale storm events in winter and spring and more precipitation falling as rain instead of snow. Some projections show an increase in the most intense summertime convective storms with the potential for a longer duration between extreme events, though there is less confidence in this result. All these factors could increase contaminant loading from stormwater flows, increase the potential for flooding, and increase the potential for septic contamination as areas previously thought to be outside the flood zone are now vulnerable to inundation. Water chemistry is sensitive to direct impacts of climate change such as change in temperature. Finally, higher average temperatures will result in higher temperatures in streams and lakes, potentially leading to more algal blooms in drinking water supply reservoirs.

Vector-borne illness: Future impacts to vegetation and average/extreme conditions are likely to affect the habitat suitability for difference disease vectors and reservoirs, such as mice, birds, mosquitos, deer, and bats (Ebi et al., 2008). As a result, new vector-borne illnesses could be introduced to the county, and/or there could be increased incidence of vector-borne illnesses that are already present. For example, rabies transmission could increase if warmer temperatures result in reservoir species (bats, skunks, etc.) spending less time hibernating and more time interacting with other animals/humans. Incidences of plague and tularemia have the potential to increase if winters become warmer and rainier on average. Milder weather in the winter seasons and warmer weather in the summer could make the county a more suitable habitat for some mosquito species, while increases in precipitation associated with extreme events could produce more habitat for mosquitos (e.g., *sp. Aedes*) that have a lifecycle linked with flooding. On the other hand, drier conditions could limit mosquito populations.

Immediate threats to mortality and morbidity: These are events that produce potentially life-threatening conditions. See Section 2.5, Impacts on Emergency Management, for specifics.

2.7 Impacts on Agriculture and Natural Resources

Agricultural impacts: Climate change can have varying impacts on agriculture, depending on crop type and location. Higher CO_2 levels generally tend to cause plants to grow larger and become more water efficient. However, for crops already near their maximum heat tolerance, more irrigation might be necessary to reduce heat stress. Because of a reduction in the time between when the seed grows and the plant matures, a number of crops, including wheat and corn, might show decreasing yields with increasing temperatures. In terms of grazing, rising temperatures might increase the length of forage production seasons but reduce forage quality, leading to a net increase in area needed to accommodate grazing animals. Lengthening growing seasons, however, could reduce the need to accumulate winter forage.

Ecosystem impacts: Changes in temperature and precipitation patterns and extremes can lead to the local extinction of species if key physiological thresholds are exceeded. In response to warming, many species are expected to shift their ranges northward and upward in elevation. Climate change also is likely to alter the timing of key events in species or ecosystems. Changes include earlier bud burst, flowering, emergence from hibernation, migration, and breeding. When these phenological changes affect co-occurring species, they can disrupt species interactions, including predator-prey and plant-pollinator relationships. As with native plant species, weeds are likely to be affected by climate change, but it is difficult to predict whether any given invasive species will do better or worse under elevated CO_2 and climate change.

Forest disease and wildfire: A combination of factors can contribute to increases in pest outbreaks under climate change. Higher temperatures can contribute to increased survival and productivity of pests, while drought and heat stress caused by climate change can make forests more vulnerable to insect outbreaks. These dynamics can affect wildfire dynamics and also provide a positive feedback to climate change. Seasonality of average and extreme temperatures and precipitation has a significant impact on wildfire timing, frequency, and magnitude. If climate change leads to warming, as anticipated, and possibly to drier conditions, this could affect the severity and frequency of wildfires, requiring alterations in fuels treatments and fire management practices.

2.8 Recommendations for Future Study

Chapter 2 of this report summarizes the state of the science on climate change applied to Boulder County. There are few studies in the literature that apply specifically to Boulder County, so we have drawn inferences from regional studies, from general principles of climate science, or from existing downscaled datasets. Climate science research is funded primarily at the national level and advances in climate modeling occur at national centers. It is essential to recognize that the uncertainty about the future climate described in this report will not likely be significantly reduced in the near future. We recommend that Boulder focus on the application of existing climate projections to Boulder County's needs.

2.8.1 Periodic review of the state of the science

Climate science is evolving, new climate projections are becoming available, and new understanding of how the natural and built environments respond to change is emerging. We recommend that Boulder County and the City of Boulder periodically review the state of the science. The year 2013 will see two important events. The U.S. National Climate Assessment will release its report on climate change impacts, adaptation, and mitigation, which will include sections based on geographic regions and economic sectors. In addition, the IPCC will release its Fifth Assessment Report. One mechanism for a periodic review could be through invited speakers from Boulder's community of climate scientists to address topics of interest to Boulder planners and decision-makers.

2.8.2 Develop and strengthen connections with the climate science, impacts, and adaptation research community in Boulder

Boulder has the greatest concentration of climate science in the world, including many resources available to Boulder County and the City of Boulder at NOAA, NCAR, and the University of Colorado. In addition, several federal agencies have research centers in Colorado including the USFS Rocky Mountain Research Station in Fort Collins and the Bureau of Reclamation and the U.S. Geological Survey (USGS) in Denver. We recommend that the city and county develop and maintain a list of science contacts who are working on topics related to Boulder County issues as defined in this report. We also recommend a point of contact be identified for climate change to work with these experts on climate science and coordinate activities across county entities regarding research.

2.8.3 Explore partnering with researchers where gaps in knowledge can be addressed with further research

Some of the gaps in knowledge identified in this report cannot be filled through simple data analysis but may require longer-term research projects. One way to accomplish this is to explore partnering with local and regional researchers. This partnership could take many forms, including participating in proposal writing to the National Science Foundation, the Water Research Foundation, and other agencies; in-kind participation to provide the stakeholder perspective in a research project; directly sponsored research; and collaboration with graduate teaching faculty at local universities on student research projects.

2.8.4 Conduct a comprehensive climate information needs assessment across departments and other entities in Boulder County

The climate chapter of this report presents basic, foundational information about the future of Boulder County's climate. The use of climate information is most successful where it can be presented in the context of existing and ongoing planning activities. This report indicates that there is significant diversity across departments and entities in the county in the current use of climate information. However, this report did not conduct a comprehensive climate information needs assessment. We recommend such a comprehensive needs assessment to inventory how information about the present climate is being used, including formats of data, climate variables used, spatial scales, and other information on how projected climate may most effectively be incorporated into individual department's planning processes. For example, some departments may use geographic information systems (GIS) layers, others may use area-average temperature and precipitation, while others may require data at individual sites.

2.8.5 Consider developing guidelines on how climate impacts studies are to be implemented in order to provide some measure of consistency across departments

While the needs for climate information may be diverse, some general, but flexible guidelines would help to provide consistency. Some recommendations could include common choice of emissions scenario(s) and investigation of future climate scenarios from more than one model. A set of general guidelines worth consideration is presented in Mote et al. (2011).

2.8.6 Develop projected climate data, and derived products, in formats that are useful to the various departments, to serve the preparedness needs identified in this report

For some needs, the climate projections presented in this report may suffice. However, other needs may better be served through maps or GIS layers of quantities such as growing degree days or number of days with temperatures above a certain threshold. It is important to understand the limitations of downscaled data, and that many decisions can be informed by drawing inferences from observed and projected changes at larger geographic scales. Several online resources are becoming available to facilitate these analyses, including statistically downscaled climate and hydrologic model output (LLNL, 2011; USGS, 2011). Analyzing regional climate model output remains labor intensive, but may be called for where specific information is needed. Some analyses that could be done with these new resources include a more detailed evaluation of snowpack distribution under warmer climates, and providing inputs to model potential impacts on vegetation including analysis of ecosystem productivity and biodiversity.

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3. Water Supply

Like much of the western United States, the delivery of water supplies in Boulder County is primarily the responsibility of individual public water providers (i.e., each city within Boulder County) and private ditch and reservoir companies. Boulder County has very little formal role in the provision and protection of water supplies across its domain. The county's Water Quality Program, part of the Department of Public Health, exercises regulatory authority over septic systems in unincorporated parts of the county and plays a role in source water protection, and the Boulder County Parks and Open Space (BCPOS) Department owns shares in ditch companies associated with the county's ownership of agricultural lands. On the whole, however, the vast majority of responsibility for ensuring adequate and safe water supplies is in the hands of municipal water utilities, water districts serving unincorporated areas of the county, ditch companies serving agricultural and other water users, and individual water wells.

The diversity of this sector is reflected in the size and complexity of various municipal water providers' systems, which range greatly based on the number of people or area of land serviced. In proportion to their population size, Boulder and Longmont have relatively large water utilities in terms of both number of taps serviced and size of staff, while mountain towns such as Allenspark and Jamestown have very small drinking water systems. As another example, the Left Hand Water District serves a geographically large section of the county between Boulder and Longmont but only about 19,000 customers (Left Hand Water District, 2008). A large number of private ditch and reservoir companies, many of which have their ownership split among private, municipal, and industrial interests, provide additional water diverted from streams and creeks throughout the county.

The provision of water in Boulder County is dependent on precipitation, particularly the accumulation and melting of snowfall in the high mountains. Most of the precipitation in Boulder County occurs as snowfall during the winter and early spring months in the higher elevation headwaters of the county. Snow accumulation usually reaches its maximum in April, and snowmelt usually occurs from April through July. This pattern of snow accumulation and melt provides a natural form of water storage that produces relatively high streamflows during May through July, which partially coincides with peak water demands associated with agricultural and outdoor urban water uses.

This chapter focuses solely on the provision of water supplies to city and county residents and farmers on county land. Some issues related to stormwater and flooding are discussed in Chapter 4. Here we will briefly review potential climate change impacts on water resources. A more in-depth discussion of hydrology under a changed climate is provided in Chapter 2. This chapter focuses on decision support by building on discussions of climate change impacts, with an analysis of specific challenges and opportunities facing water supply entities in Boulder

County. The analysis is based on scientific literature, an examination of various water supply planning documents, and interviews with representatives of the City of Boulder Public Utilities Department, the Boulder County Water Quality Program, the City of Lafayette, Left Hand Water District, and BCPOS.

3.1 Why Consider Climate Change?

Climate has significant impacts on the balance of water supplies and demands throughout Boulder County. The amount of water available to meet human and many other needs across the county is directly related to the amount and timing of snow accumulation and snowmelt in the high mountains of the county. Rainfall during spring and summer months supports the growth of natural vegetation and some crops on the plains, and temperature affects human and agricultural water demand across the county and in downstream areas.

In this section, we first discuss potential climate change impacts on water supplies and demands throughout the county. Next, we analyze the degree to which climate change could affect the fundamental goals of water supply entities throughout the county and describe specific challenges they might face.

3.1.1 Impacts of climate change on water supplies in Boulder County

Overall precipitation: Total available water is directly related to the amount and timing of snow accumulation and snowmelt in the high mountains of Boulder County. As noted in Chapter 2, the climate of Boulder County is highly variable and strongly influenced by elevation and topography. The high mountains on the western edge of the county collect significant snowpack that melts and runs off into the plains, providing the bulk of water supplies for most utilities and other providers. Climate change impacts on overall precipitation in Boulder County are unclear, although there is some evidence that precipitation will shift earlier, with more snow falling December through March and less falling in April and May. Modeled future climate projections show no clear trend in annual, summer, or fall precipitation.

Snowmelt and streamflow: Rising temperatures are expected to result in a partial shift from snow to rain, reducing snowpack levels, which serve as natural wintertime water storage, and accelerating the timing of runoff. This means more runoff in late winter and early spring and less runoff in late spring and summer. A significant reduction in snowpack might force some water providers to look for additional artificial storage (staff interview), although the high elevation of many of the county's watersheds might mitigate shifts to rain.

East Slope supplies: There is some indication that wintertime precipitation might increase and summertime precipitation might decrease, especially in the mountains that yield snowmelt to streams on the East Slope in Boulder County. However, there is little agreement among the multiple climate models considered and much uncertainty surrounding the ability of models to properly demonstrate the effects of mountains on precipitation patterns. In 2009 the City of Boulder partnered with consultants and obtained a federal grant to study the vulnerability of the city's water supplies to climate change. Except under the driest future scenarios analyzed, the city was capable of meeting their reliability goals. However, similar analyses have not been done for other county water providers.[5] Thus, planning for climate change will entail preparing for uncertainty, since neither global nor regionally downscaled climate models provide a clear picture of future changes in precipitation across the county, as discussed in Chapter 2.

Colorado River Supplies: The 2009 Boulder study factored in potential impacts to the city's water supplies that come from the Colorado River. Boulder, like many water utilities in the county, owns units of the Colorado-Big Thompson (C-BT) project, a federal trans-basin diversion that brings water from the Colorado River to Front Range communities. Thus, water supplies in the county are impacted by climate in the headwaters of the Colorado River, which can affect the amount of water available to be transferred through the C-BT project. It is critical to recognize the high level of correlation between droughts in the headwaters areas of both Boulder Creek and the Colorado River (City of Boulder, 2004), which might reduce the ability of water providers to use C-BT water as a means of diversifying supply. One unknown but potentially significant impact on water providers reliant on C-BT water is the possibility of a Lower Basin call (request for more water) under the Colorado River Compact, which would reduce the amount of water available to users in Upper Basin states including Colorado (City of Boulder, 2009).

Extreme precipitation and flooding: Extreme precipitation, especially late spring storms, can lead to heavy flooding that can negatively impact water quality and storage (staff interview). Temperatures also impact water supplies and demands – warmer conditions can lead to greater water demands from agricultural and outdoor municipal uses and increased evapotranspiration from reservoirs. Changes in temperature and precipitation manifest in streamflow, which can in turn impact other aspects of water supplies, including water quality – for example, lower streamflows often result in higher concentrations of pollutants (staff interview).

5. Small water providers lack the personnel or funding to spend significant time assessing climate change impacts or preparing for a significantly different climate in the future (City of Lafayette staff interview).

Rising temperatures would also increase the likelihood of rain-on-snow events that could raise the likelihood of flooding.[6] Floods can have serious consequences for water supply management by bringing massive amounts of sediment and debris through creeks and into reservoirs. Under those conditions water managers often decide not to capture the water due to its low quality and might have to contend with reservoir damage (staff interview). In addition, an increase in the magnitude and frequency of sediment (debris) flows will increase the risk of damage to vulnerable water supply infrastructure. These highly erosive events can readily scour down to and dissect buried pipelines as well as knock down buildings.

Drought and variability: The City of Boulder relies primarily on snowpack in the watersheds feeding Middle and North Boulder creeks for its water supply. Boulder uses additional water from the C-BT system, some of which is exchanged with farmers to allow the city to use more water from the upper reaches of Boulder Creek, which generally has higher quality and can be diverted by gravity to the city's treatment plant. Thus, the city pays close attention to snowpack in late spring, which can be a significant indicator of how much water will be available throughout the rest of the year. During the 2002 drought, for example, the city was able to determine from its regular measurements of snow depth that it would be a particularly dry year and began implementing drought restrictions (staff interview). Future extended droughts that impact snowpack in the high mountains – especially if such droughts reduce the frequency or size of spring upslope storms – could push the city into more severe drought restrictions. However, city water managers are currently comfortable with their ability to use existing supplies as well as emergency storage to meet needs even under very usual drought circumstances (staff interview). Other water supply entities in the county were able to deal with the drought but are not necessarily as comfortable with the possibility of longer-term or more severe droughts.

Water supplies for county agricultural lands: BCPOS owns water rights across the county, associated with its ownership of agricultural land through the Open Space program. Approximately 12,000–13,000 acres of land are irrigated each year, using up to 26,000 acre-feet of water per year when supplies are available. Various ditch companies control the water used on county agricultural lands, and BCPOS owns at least some share in all of the companies serving county lands (staff interview). With the exception of very senior water rights at some properties such as Caribou Ranch, much of the water rights for county-owned agricultural lands are from the 1870s, which make them junior to some downstream rights holders on the South Platte. Thus, farmers on county lands often find themselves with insufficient water for irrigated crops,

6. Rain falling on snowpack can have a variety of impacts depending on conditions prior to the rain event. In general, however, because rain adds thermal energy to snowpack, it can speed up snowmelt. In addition, frozen soil underneath snowpack absorbs little water, leading to faster runoff, which could potentially lead to flooding. Rain-on-snow is currently a much more common phenomenon in the Pacific Northwest and the Sierra Nevada mountains than it is in the Colorado Rockies.

especially during particularly dry years when cities and other holders of more senior rights call for water (staff interview).

Water quality impacts: Temperatures have increased across Colorado over the past 30 years and are projected to increase during all months of the year but especially during the summer (Ray et al., 2008). This could result in earlier runoff and reduced summer and wintertime flows, potentially exacerbating water quality problems. As flows decrease, the concentration of metals, sediment, or other contaminants increase in a given surface water body, reducing the water quality and creating the need for greater water treatment to meet applicable quality standards (staff interview). A warmer climate is likely to also increase water temperatures, which can have a number of negative impacts on aquatic ecosystems. For example, warmer temperatures could increase the amount of organic matter such as algae in source water, which would consequently increase the presence of disinfection by-products that are costly to remove in order to meet water quality standards (staff interview).

Warming temperatures are also associated with an increase in wildfire frequency and magnitude throughout the western United States (Westerling et al., 2006). Intense wildfires can produce highly erodible soils that can lead to increased sediment loading in reservoirs and streams, damaging water infrastructure and degrading water quality. Although most of the city's water supplies are in low or moderate fire risk areas (City of Boulder, 2009), a catastrophic fire would have serious impacts on higher-elevation water supplies, notably Barker Reservoir. In addition, the placement of the City of Boulder's main water treatment plant at Betasso leaves it vulnerable to fire – during the Fourmile Canyon Fire, the city was nearly forced to evacuate and shut down the Betasso Treatment Plant, which would have resulted in a loss of treated water entering the city (staff interview).[7]

Impacts to water demand: Higher temperatures generally result in increased demand for water use in outdoor landscaping and agricultural irrigation. For many water supply entities, a warmer future could lead to an increase in demand as residents use more water on their lawns and crop irrigation water requirements increase. However, the prior appropriation water rights system complicates this connection for the City of Boulder. Changes in demand within its water supply service area are less stressful to the system than increases in demand from agricultural users along the South Platte whose water rights are senior to those held by the city (staff interview). Under Colorado's prior appropriation system, agricultural water users on the plains along the South Platte River downstream of Boulder County are entitled to water flowing through the county during times of insufficient supply to the degree that their water rights are senior to those of county municipal utilities. Thus, increased water needs for plains agriculture, especially

7. The water treatment plant is connected to a specialized computer control system intended to allow the plant to be operated remotely, but it did not work properly during the Fourmile fire.

during drought, can have significant impacts on the availability of water for municipal and industrial uses in the county.

Additional non-climate impacts: Non-climate concerns are also relevant to water quantity and quality and can interact with climate impacts. Water managers are particularly concerned about pollution from septic systems near water supplies. Although the City of Boulder owns a portion of its watershed, urban runoff in Nederland and drainage from abandoned mines can affect water quality in Barker Reservoir, which provides significant storage for the city. Many water providers depend on the Boulder Feeder Canal to bring C-BT water from Carter Lake. However, runoff from nearby agricultural lands often reduces the quality of water in the canal, which is why several water providers are considering building the Carter Lake Pipeline (staff interview). In addition, companies have begun to seek permits for hydraulic fracturing (known as "fracking") for natural gas in the eastern section of Boulder County. Although the impact of fracking on water supplies in the county is largely unknown at this point, produced water from wells could pollute shallow aquifers or ditches in the event of a spill or other mishap (staff interview). Water utilities are also subject to a large number of federal and state regulations and often struggle to pay for and comply with increasingly stringent regulations (staff interview).

Although many western communities are concerned with the ability to provide adequate water supplies to growing population centers, that does not seem to be a major concern for many Boulder County municipal water providers. The City of Boulder, which currently serves 113,000 residents and 100,000 employees, is already near its build-out expectations of 129,600 residents and employment of 166,000 (City of Boulder, 2009). The City of Lafayette is at 70% of its projected residential build-out (staff interview). Open space acquisition and other factors have made population growth a less significant issue for some water providers in the county. Although most utilities require developers to pay for water infrastructure needs, development can force the construction or upgrading of treatment plants and other major infrastructure sooner than a utility is prepared for (staff interview).

Finally, political considerations seem to be a significant stressor for water providers in the county. Water providers thinking about the future often wonder whether they will need additional storage to meet population growth, handle variability, and adapt to a future with less snowpack and lower summer flows. However, the political climate in Boulder County has been described as hostile even to discussions of expanding storage or building new reservoirs (staff interview). Left Hand Water District has found the county's approval process for laying new pipeline to be extremely cumbersome and based on a presumption that the District is encouraging growth (staff interview). In the City of Boulder, some residents and officials believe that water is directly connected to growth and thus push for water to be provided on an "absolute yield" basis,[8] rather than through the city's existing reliability criteria (staff interview). Finally, water utilities – particularly the City of Boulder – often own aging infrastructure that requires costly maintenance and repair, but obtaining funding for major infrastructure projects requires City Council approval of rate increases, which might be held up due to political considerations.

3.1.2 The effects of climate change on water supply objectives

Water utilities in Boulder County, it should be noted, are accustomed to planning for and managing highly variable systems. For example, the City of Boulder is accustomed to dealing with creek levels that can fluctuate on a 24-hour basis during the summer, along with severe storms in both the winter and summer (staff interview). Recent droughts, particularly the severely dry year of 2002, also tested water providers' abilities to manage demand and meet critical needs. The City of Lafayette noted very good compliance with drought restrictions that summer, which enabled them to reduce outdoor water use by approximately 80% (staff interview). The Left Hand Water District implemented some water use restrictions but found itself with plenty of water to meet customer needs (staff interview), even though the 2002 drought was considered a 1-in-300-year event when compared with tree-ring records (City of Boulder, 2004).

Despite that, however, water supply entities throughout the county are still vulnerable to major shifts in climate trends that can affect planning, especially due to the long time frames used by municipal water utilities. The City of Boulder uses both a 20-year short-term and a 100-year long-term planning horizon (staff interview). The City of Lafayette plans for 50-year intervals, timed with the operational life of a water treatment plant (staff interview). Every 10 years, the Left Hand Water District updates its master plan, which anticipates needs over the next 20 years (staff interview). Given the long time frames involved in water supply planning, utilities and other providers must take climate trends into account in order to properly forecast available supplies and demands so that they can meet their objectives.

We describe the objectives of water supply entities in the county here in order to ensure that climate change is viewed as a potential factor affecting their ability to meet their objectives, rather than a separate impact requiring separate plans and management. Given the large number of public and private water supply entities in Boulder County, it is not possible to describe the objectives of each one in this document. However, most municipal and domestic water providers have a mission or set of goals that focuses on the timely and economical provision of safe, clean

8. Under an "absolute yield" system, water would be provided to meet any demands within the service territory unless emergency conditions exist. In contrast, the City of Boulder's reliability criteria promises water delivery only to specified needs when the city experiences various drought conditions.

water to their customers. Private irrigation companies are focused on delivery of adequate supplies of a quality suitable for their respective shareholders' uses.

As an example, the City of Boulder's 2009 Water Utility Master Plan (City of Boulder, 2009) lists overall water utility goals as:

- Provide safe and high-quality drinking water
- Minimize interruptions to the delivery of water
- Operate cost effectively
- Consider other community goals in operating the water utility
- Provide informative and responsive customer service
- Foster communication and coordination among water utility staff in different locations.

Individual portions of the city's utility system, such as the water treatment facility, have more specific sets of goals and objectives.

The City of Lafayette's water utility, which serves approximately 8,000 residential and commercial customers, is guided by an informal two-tiered set of objectives – their first priority is to provide clean water for the safety and health of everyone within the service area. The secondary priority is to provide water to benefit customers' quality of life through irrigation of landscape and other uses (staff interview).

The Left Hand Water District, an enterprise operation first formed in the early 1960s, describes its mission as providing "safe and reliable water to our community in an economical, efficient, and responsible manner now and in the future" (Left Hand Water District, 2008).

The county's Water Quality Program shares the objective of its parent division, the Environmental Health Division of Boulder County Public Health (BCPH), which has a vision of "a safe, clean, and healthy environment for Boulder County" (Boulder County, 2011). The Water Quality Program in particular strives to ensure that county residents have the best water quality possible (staff interview).

BCPOS has an extensive set of objectives, which are discussed in Chapter 6. A 2008 draft BCPOS Water Policy describes a vision of water resources "managed in an effective, sustainable, and efficient manner to support agriculture, provide quality visitor use opportunities, maintain viable riparian corridors, and for other environmental benefits," with specific goals related to agriculture, ditch operations, riparian habitat, reservoirs and ponds, visitor experience, information management, and monitoring and maintenance (BCPOS, 2008).

We use the first three goals listed in the city's overall plan as a basis for analyzing water supply entity objectives under climate change. The remaining goals are less relevant because they are specific to the city and less influenced by climate factors.

Provide safe and high-quality drinking water: This broad goal, which is similar to the overall objectives of other water supply entities considered in the preparation of this report, encompasses concerns about both quantity and quality of water supplies. Under climate change, the ability of water supply entities to deliver as much water as they have in the past might be compromised. Water supply entities generally plan using the historical record of variability, which in Boulder County extends back approximately 150 years. If climate change results in a reduction of water available on average, water supply entities might have to change their planning in order to adapt. Although most water supply entities are prepared for changing operations to accommodate year-to-year changes in availability, a trend in overall supply will require reconsidering long-term plans and examining costly and difficult options.

In addition, climate change might hinder the ability of water supply entities to deliver safe and high-quality water. Although none of the water providers interviewed as part of the preparation for this document expressed concern that they would be unable to meet quality standards set by the State of Colorado, they are worried about the possibility that lower late-summer flows could result in more frequent violations of water quality criteria or require the installation of expensive treatment equipment. The possibility of increased frequency of floods, fires, and other extreme events also poses a threat to achieving this objective by potentially reducing water quality. Finally, increased temperatures, especially late in the season when reservoirs are low, can result in increased algae, which in turn requires greater use of chlorination and will lead to higher levels of disinfection by-products after raw water is treated (staff interview).

Minimize interruptions to the delivery of water: This goal primarily deals with reducing the number of water supply interruptions attributed to distribution pipes bursting underground. Due to the significant freeze-thaw cycle in Boulder County, water pipes in the county are buried several feet underground and protected from most climate impacts. However, extreme events, especially fires and floods, can in some rare cases impact the delivery of water supplies, as discussed elsewhere in this chapter.

Operate cost effectively: As mentioned in the discussion of the first objective, changes in average streamflow or other variables that affect the availability of water supplies might require the consideration of long-term adaptation steps. These steps can include the construction of new storage or the acquisition of additional water rights, both of which would result in additional costs to water customers. Impacts to water quality might require water treatment plant upgrades that can also be costly, although the increasing stringency of federal water quality regulations makes that a concern regardless of climate change (staff interview). Extreme events can potentially damage water supply infrastructure, resulting in needed repairs whose costs will be borne by customers or shareholders.

3.1.3 Key future management challenges for water supply entities

Any change that reduces the average amount of snow that falls or that affects the timing of snowmelt and associated streamflow patterns would affect the availability of runoff to meet seasonal water demands throughout the county. Although water providers in the region are accustomed to the vagaries of climate, long-term droughts or shifts in the timing of seasonal streamflow patterns, caused or exacerbated by climate change, could hamper the ability of water providers to have enough water available to meet customer needs with minimal interruptions. Thus, a key management challenge is anticipating potential long-term shifts in annual precipitation and water availability and planning for the flexibility to address those shifts.

The City of Boulder's four options for adaptation in case of a major reduction in water availability can be generally described as (1) acquiring additional water rights; (2) building additional storage; (3) changing reliability criteria; and/or (4) changing the standard of public expectations for water service (staff interview). Given the constraints of Colorado's prior appropriation system and the seasonal nature of water supplies in this region, even these options are relatively constrained. Understanding which ones apply or might be politically palatable to specific water supply entities is critical to assessing the full range of options available for water supply adaptation throughout the county.

Finally, dealing with the fact that a number of "different futures" are possible poses a major challenge to water supply entities in the county. A future of reduced overall precipitation, warmer summers, and greater demand downstream of the county will cause much more stress to water supply entities here than would a future with greater winter precipitation and steady downstream demands. Being able to plan for the possibility of either of those futures – or a multitude of other scenarios – without overcommitting capital and other resources is a serious and difficult issue facing water supply professionals in the county.

3.2 Opportunities to Address Climate Change

There are a number of opportunities for Boulder County and the City of Boulder to integrate adaptation to climate change into planning, management, and operations of municipal water supply entities. The following sections consider these opportunities, including high-level information resources, connecting disaster planning with water supply vulnerability, discussing the need for investment in water efficiencies, "no-regrets" adaptation strategies, and opportunities for public and stakeholder education on climate change.

3.2.1 Sharing information, expertise, and resources

Given that water providers in the county are accustomed to planning for and managing variability, the key is ensuring that they are prepared to deal with a future where climate change has pushed both overall trends and the magnitude of individual weather events beyond what has been experienced in the history of settlement of the county. Within and near Boulder County are a tremendous number of scientific and technical resources that could be leveraged to help water providers better understand and plan for the impacts of climate change on water resources.

As mentioned earlier, the City of Boulder has completed a study of the vulnerability of its water supplies under various climate change scenarios. Several years earlier, the city used tree-ring records to construct a paleohydrology record for streamflow in Boulder Creek, providing a better idea of the range of variability in the climate even before anthropogenic climate change. These studies have given the city a range of futures to consider in planning (staff interview). Although both studies relied on a model of the city's water supply system, general findings about the magnitude and duration of past droughts and a possible range of climate futures could be relevant to other water providers in the county.

In addition, Boulder is home to two federal laboratories (NCAR and NOAA's David Skaggs Research Center) with a vast amount of climate expertise and modeling capacity, along with high-level climate and weather research conducted at the University of Colorado. Developing connections to these resources – and finding ways to provide science translation for water managers – could go a long way toward ensuring that even smaller water providers are aware of and can react to information about the future impacts of climate change on water in the county.

This creates an opportunity for the county to provide a new role in facilitating adaptation among water providers. Many water providers lack the staff or resources to plan for climate change the way Boulder or Denver Water do, but they do strive to pay attention to the implications of climate change on water resources (staff interview). Smaller water providers could benefit from additional opportunities to learn about potential climate change impacts and adaptation options considered by their larger counterparts. The county has a significant opportunity to address this issue by creating forums for information sharing, connecting small water providers with academic and government resources, and even potentially by considering the option of hiring a climate science translation specialist, who could help individual county water providers access and act on relevant scientific and technical information.

3.2.2 Focusing on water quality

On a national scale, a significant amount of attention has been devoted to understanding and preparing for climate change impacts on streamflow and water availability, with much less attention paid to impacts on water quality. This appears to be reflected in the City of Boulder, where extensive effort has been put into assessing the vulnerability of the city's water supplies to climate change and preparing for severe droughts. The city's Drinking Water Program, however, is only beginning to assess its potential vulnerabilities with a foundation-funded multi-utility study of the impacts extreme weather can have on water quality.[9] Utility staff responsible for drinking water quality, however, understand that there could be a host of other climate-related impacts that at the least would be expensive to treat. The county's Water Quality Program is in a prime position to work with the city and other water providers to assess water quality vulnerability to climate change in the area and determine whether putting additional resources into preparing for warmer stream temperatures and other possible climate impacts is warranted. This would logically fit with the city's potential development of a source water protection policy, as recommended in its Water Utility Master Plan (City of Boulder, 2009).

3.2.3 Integrating emergency management and water system planning

The City of Boulder's recent experience with the Fourmile fire's impact on water treatment indicates a clear link between EM and water system planning. There is a significant opportunity for emergency managers and water utility operators to ensure that continuity of a safe water supply is part of EM planning and that emergency responders are capable of assisting the water utility as necessary. In addition, as mentioned in the city's Water Utility Master Plan, there is no comprehensive emergency response plan addressing how to get water supplies back online in the event of a disaster (City of Boulder, 2009). The city should develop such a plan and coordinate it with the Boulder County Office of Emergency Management's (OEM's) response and recovery efforts to ensure that there is a plan for getting clean water to customers as soon as possible in the event a disaster causes a disruption. Other municipalities within the county should consider similar efforts if warranted.

9. Boulder is part of a group funded by the Water Research Foundation to look at "Water Quality Impacts of Extreme Weather-Related Events." The project is expected to be complete by the end of 2013 (City of Boulder water quality staff interview).

3.2.4 Public education about climate and water system variability

Water utility managers have indicated a lack of understanding among the public and some decision-makers about the complexities of water delivery in the county. For example, the City of Boulder has realized that it is actually advantageous not to aggressively conserve water during peak streamflow because greater flow through the city's supply system increases hydropower generation and allows for recharge of the alluvial aquifer for Boulder Creek that supports instream flows and provides greater "return flows" later in the summer (staff interview).[10] In addition, some decision-makers appear to be concerned that Boulder will get much drier in the future, although the science does not give such certainty at this point (staff interview). Given the uncertainty in trying to project future precipitation in the county, along with the variability already inherent in our regional climate system, it is prudent to implement plans and policies that allow water systems to be resilient and meet objectives under a range of possible future climates. The City of Boulder's water system vulnerability study recommends doing so (Smith et al., 2009), and that type of approach should be incorporated into all water system planning across the county.

In addition, future water system planning might need to incorporate more community discussion about various options related to adaptation. The City of Boulder's options for water supply adaptation, described above, are all potentially politically sensitive issues. The city and county would benefit from beginning public dialogues on the pros and cons of various options that could enhance water providers' abilities to prepare for and adapt to climate change.

3.2.5 Investing in "no regrets" infrastructure projects and water rights

As mentioned in Chapter 1, a key element of adaptation to climate change is engaging in "no-regrets" decisions that provide benefits regardless of the state of the climate in the future. This is particularly relevant with respect to water supply. A robust system capable of handling a wide variety of streamflow scenarios, along with policies and plans that dictate responses to drought, floods, terrorist attacks, and other extreme events, is the best preparation. A primary example of a "no-regrets" strategy would be the Carter Lake Pipeline, otherwise known as the Southern Water Supply Pipeline, which would replace the Boulder Feeder Canal that carries C-BT water from Carter Lake. Water in the canal is currently subject to pollution from agricultural runoff and other sources, so installation of the pipeline would reduce the influence of those sources and help mitigate possible worsening of water quality problems in a future of lower late-summer flows (staff interview; City of Boulder, 2009).

10. "Return flows" refer to water that returns to a stream later in the year after being used on land for a given purpose.

In addition, the City of Boulder has recently taken a "no-regrets" strategy by amending city code so that the city retains first right of refusal for the purchase, upon granting of a water tap, of private water rights currently used within the city. This action could help protect the approximately 5,000–7,000 acre-feet of ditch rights within city limits vulnerable to being sold outside the utility's service area. By exerting greater control over these rights, the city is bolstering its ability to easily increase supply at relatively low cost using local options rather than potentially affecting more distant agricultural areas (staff interview). Regardless of whether or not climate change reduces water availability for the city, this strategy provides benefits to the city, including greater local control over nearby water.

3.2.6 Sustaining adaptation knowledge in county agriculture

BCPOS has long recognized the junior status of many of its water rights and the potential vulnerability of irrigated farming on county land under a future of earlier snowmelt and warmer summer temperatures. It relies primarily on tenant farmers' understanding of water in the region to ensure that farms on county land stay viable during dry years. In addition, BCPOS has invested and continues to invest heavily in efficient irrigation equipment, including center-point irrigation devices and planting more water-efficient varieties of crops when available (staff interview). Continuing to recognize the value of water efficiency investments is key to ensuring that county agriculture will remain viable in a more water-constrained future.

BCPOS also recognizes the critical value of local knowledge about water and agriculture in this region possessed by third- and fourth-generation farmers working on county open space land (staff interview). There is a clear opportunity for the county to continue to work with the Colorado State University Agricultural Extension Service to pursue educational opportunities for new farmers and to press existing farmers to identify succession plans to avoid losing critical knowledge. Climate preparedness in county agriculture will likely be contingent upon continuing generations of experienced farmers capable of understanding local conditions and being flexible in the face of highly variable and potentially fundamentally different water availability.

3.3 Policy Recommendations

Based on our archival review and interviews, we present our synthesis of a few policy recommendations for water entities in Boulder County. These recommendations are intended as immediate action items that can help prepare municipal water agencies for climate change.

3.3.1 Create a climate adaptation learning network for water

Boulder County should establish a climate adaptation learning network focused on water to allow smaller water providers to learn from larger ones. The network should explore ways to leverage county resources to aid utilities with small staff in assessing their climate change vulnerabilities and planning for future possibilities. It should also connect utility managers with local climate and hydrology experts and other water managers along the Front Range, possibly leveraging the network built by the Joint Front Range Climate Change Vulnerability Study.[11]

3.3.2 Provide a means to translate and communicate climate science

Boulder County should consider hiring a new position or assigning an existing staff person with the task of translating relevant climate science for water utilities and encouraging them to plan for the possibility of a significantly different climate in the future. Note that Denver Water has such a staff position.

3.3.3 Plan for a variety of different climates

City and county officials should be aware of the uncertainty inherent in climate change projections and prepare to adapt to a variety of future climates, rather than assuming the climate will move in one particular direction.

3.3.4 Ensure funding and support for "no-regrets" projects

Municipal elected officials in charge of funding water infrastructure projects should acknowledge and make use of the co-benefits from improving water supply infrastructure, which can both meet current needs and help ensure systems are better able to cope with future climate change. Infrastructure decisions should be made with a "no-regrets" framework in mind.

3.3.5 Provide a forum for community dialogue on water and climate

As noted above, the City of Boulder's options for dealing with future water supply shortages are likely going to involve some combination of acquiring additional water rights, building additional storage, changing reliability criteria, and changing the standard of public expectations for water service. Most municipalities in the county do not have the luxury of adjusting

11. The City of Boulder is a participant in the Joint Front Range Climate Change Vulnerability Study, and Longmont is an observer.

reliability criteria, limited their options even further. To better set the stage for possible actions in the future, the county and individual water providers should foster community dialogues around the pros and cons of various options for adapting to climate change. In particular, citizens and elected officials should carefully consider the merits and perils of expanding water storage, especially in areas with relatively little storage.

3.3.6 Coordinate with emergency management officials

Water managers should coordinate clearly with EM officials on disaster mitigation and recovery and they should work with the county as it moves forward with developing post-disaster recovery planning efforts. Being ready to respond to a disaster that interrupts the supply of clean water to residents is critical to mitigating the after-effects of natural and other hazards.

3.3.7 Develop source water protection policies

The City of Boulder should move ahead with developing source water protection policies. At the same time, county officials should consider expanding the scope of the county Water Quality Program to assist smaller water providers in ensuring high-quality source water. Municipalities can also receive grant funding from the state Department of Public Health and Environment for source water protection planning,[12] as the Left Hand Water District has already done (Left Hand Water District, 2011).

3.3.8 Prepare for the consequences of severe wildfires on water resources

The county and municipalities within it should work with the U.S. Forest Service to prepare plans for rapid response to severe wildfire that could produce significant sedimentation into reservoirs and streams or that otherwise threaten water supply infrastructure. In addition, the county and municipalities should examine the impacts and prepare for the impacts of flame retardant chemicals on water quality in reservoirs and streams.

3.3.9 Continue public outreach on reliability criteria

The City of Boulder should consider additional public dialogue aimed at adding specifics to its reliability criteria in the event that low-frequency extended droughts require the implementation of severe water use restrictions. Although drought restrictions put into place in 2002 were generally successful, with high levels of compliance, future droughts of greater duration or

12. See http://www.cdphe.state.co.us/wq/sw/swaphom.html.

severity could lead to public concern or difficult political discussions that may work better when the city is not facing drought conditions. In addition, other municipalities across the county should consider the costs and benefits of implementing reliability criteria similar to those used in the City of Boulder.

3.3.10 Prioritize BCPOS investments in water efficiency improvements

BCPOS should continue to emphasize investments in water efficiency improvements on irrigated agricultural land owned by the county and should seek to ensure that its tenant farmers are knowledgeable about local water issues and prepared to be flexible from season to season.

3.4 Recommendations for Future Study

Many ideas and suggestions were developed during the course of our research. Interviewees and expert reviewers suggested many more. Ideas and recommendation judged premature for immediate policy action are included in this section as possibilities for further study or research.

3.4.1 Additional research on water quality impacts from climate change

The City of Boulder should expand efforts to study the potential impacts of warmer temperatures on source water quality and water treatment requirements, leveraging resources at the University of Colorado and elsewhere. The county should remain involved in these efforts to inform the county Water Quality Program and help small water providers understand implications of warmer temperatures on water quality parameters.

3.4.2 Periodic assessments of the state of science on climate change impacts to precipitation and severe storms

Ongoing research at University of Colorado-Boulder, NCAR, NOAA, and elsewhere has the potential to improve scientific understanding of how climate change will impact precipitation and storms in the Rocky Mountains. As noted earlier, current climate models do not necessarily do a good job of characterizing precipitation in mountainous areas. That may change in the future, providing Boulder County and municipalities with a better indication of future trends in both overall precipitation and runoff and the frequency of severe storms. The City of Boulder has already indicated that it plans to monitor evolving relevant science, and the county should partner with them and help disseminate information to other municipalities (City of Boulder, 2009). The county and municipalities should also follow the results of studies including the

Colorado River Water Availability Study, which will provide additional information regarding future changes to flow in the Colorado River system.

3.4.3 Leverage Joint Front Range Climate Change Vulnerability Study and other resources to develop more specific vulnerability analyses for specific water supply entities

The county should consider whether it can leverage the City of Boulder's Climate Change Vulnerability Study or Boulder and Longmont's work with the Joint Front Range Climate Change Vulnerability Study into more specific information aimed at understanding the vulnerability of smaller providers in the county.

3.4.4 Examine case studies of other water supply entities around the country that have developed approaches to planning for uncertain futures

The City of Boulder and Boulder County should study the activities of other water utilities throughout the West that have developed comprehensive plans for dealing with the uncertainty in projections of precipitation and draw relevant lessons where possible. One option is to participate in networks of water utilities that focus on providing lessons learned on adaptation.

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4. Emergency Management

Climate change has significant potential to greatly exacerbate the already significant natural hazard risk that the county currently faces. Consequently, EM was identified as a critical area of focus in this plan. This chapter also considers HM, with an emphasis on floodplain management and wildfire mitigation. EM generally consists of four phases: mitigation, preparedness, response, and recovery. Mitigation consists of those activities designed to prevent or reduce losses from disaster. Preparedness is focused on the development of plans and capabilities for effective disaster response. Response is the immediate reaction to a disaster. Recovery includes activities that help to restore critical community functions and manage reconstruction in a timely and responsible manner.

Boulder County and the City of Boulder have experienced damaging floods and wildfires in the past and, despite mitigation efforts, considerable risk remains. Other hazards that could be influenced by climate change include atmospheric hazards such as extreme temperatures, droughts, severe thunderstorms, windstorms, tornadoes, and winter storms. In addition, EM often deals with hazards that could impact human health, such as pandemic flu and West Nile virus (WNV), although those issues are addressed in Chapter 5. All of these hazards are identified and profiled in the county's Multi-Hazard Mitigation Plan. The major issue for climate adaptation planning in regards to EM is that climate-influenced disasters in Boulder County might become more frequent, intense, and hence more costly than they have been in the past.

The remainder of this chapter examines the challenges that climate change might pose to EM personnel in Boulder County. This chapter is meant as a decision-support document and translates the current scientific knowledge of climate change into possible impacts on the focal area. Multiple county and city departments contribute to EM/HM within Boulder County. The primary departments with this responsibility include the City of Boulder and Boulder County's joint OEM, County Transportation Department, County Public Health, County Land Use, and City of Boulder Utilities Division in the Department of Public Works. A review of the institutional objectives and guiding documents and policies of each of these departments was conducted to determine if there is currently an aspect of climate change adaptation within those objectives, to identify which objectives could be impacted by climate change, and to evaluate opportunities to integrate climate adaptation principles into existing plans and policies. Supplementing this were interviews with staff from the joint City and County of Boulder OEM, City Utilities Division, and County Transportation Department. The results of this analysis are discussed in the following sections.

4.1 Why Consider Climate Change?

Climate change has the potential to alter the nature and frequency of hazard events and might necessitate changes in the way in which hazards are managed as a means of adaptation. The following is a brief identification of department objectives that relate specifically to HM or EM. It is important to state upfront that climate change adaptation is not an end in and of itself for these departments. Instead, climate change must be viewed as a factor that actually or potentially affects the ability of these departments to meet their primary and legally mandated objectives. One of the basic underlying premises of the EM focal area is that mitigation of hazards is a key component of climate change adaptation and disaster resiliency. As an example, removing a property from a flood-prone area to one with lower flood risks will reduce losses from flooding in both existing and future climate scenarios. Thus, much of this chapter focuses on a review of how hazard mitigation is implemented by each department. Since the threat of climate-influenced hazards cannot be completely mitigated, the preparedness, response, and recovery capabilities within the county are also taken into consideration, as these capabilities might be stressed by severe disasters in the future.

4.1.1 Impacts of climate change on hazards

Boulder County has many existing vulnerabilities to climate-driven hazards such as floods, windstorms, wildfires, winter storms, lightning, and thunderstorms. These hazards and associated vulnerability of people, property, natural and cultural resources, and critical infrastructure are profiled in the Multi-Hazard Mitigation Plans for the county and city. The following list comes from the county's plan:

- Avalanche
- Dam and levee failure
- Drought
- Earthquake
- Extreme heat
- Expansive soils
- Flood
- Hailstorm
- Landslide/mud and debris flow/rockfall
- Lightning
- Pandemic flu
- Severe winter storm
- Subsidence
- Tornado
- WNV

- Wildfire
- Windstorm.

Under the current climate, the Multi-Hazard Mitigation Plan notes that the county has a considerable vulnerability to wildfire and flooding. Drought, dam and levee failure, landslide/mud and debris flow/rockfall, severe winter storm, and windstorm were also considered high planning significance hazards. The city is most vulnerable to floods, dam failures, and pandemic flu according to its Multi-Hazard Mitigation Plan. Wildfires have the potential to encroach into developed areas of the city and do significant damage. The City of Boulder is often referred to as having the highest flash flood risk of any community in the Colorado Front Range due to its location along Boulder Creek at the base of the Rocky Mountain foothills. The respective Multi-Hazard Mitigation Plans for the city and county provide additional details on specific vulnerabilities and potential losses for the identified hazards.

With the exception of earthquake and possibly subsidence, climate change has the potential to exacerbate the nature of all of these hazards, most notably the magnitude and frequency of the events. As noted previously in Chapter 2, climate change might result in increased frequency and severity of extreme weather events and other natural hazards. In Boulder County, those hazards include drought, flash floods, severe winter storms, tornadoes, windstorms, and thunderstorms. Currently the Multi-Hazard Mitigation Plans do not address the potential for climate change to alter the nature of these hazards. Although the direction of change in many of these hazards is known (e.g., more intense precipitation events are likely), there is uncertainty about the magnitude of change, and thus it is difficult to *predict specific changes in frequency and magnitude of specific events*. Future updates to the Multi-Hazard Mitigation Plans should include exploring how climate change might cause hazard vulnerabilities to change and possibly revisiting the level of significance of certain hazards, such as extreme temperatures, that are likely to become more of a concern due to climate change.

Disaster frequency: A concern of the Boulder OEM is the potential for more frequent disasters than the county has faced in the past. From a nationwide perspective, 2011 has been marked by a large number of extreme climate events (landmark tornados, floods, droughts, fires, and severe weather outbreaks) that have led to more than 10 presidential disaster declarations. The federal disaster relief costs for these events exceeded $1 billion as of September. Some of these events might have been influenced by La Niña conditions in the Pacific Ocean, but it begs the question as to what influence climate change might have had and if this is the start of a trend toward increasing disaster relief expenditures, 25% of which is borne by the state and local governments when a presidential disaster is declared. Although Boulder County is not directly at risk from hurricanes, other hazards, most notably floods and wildfire, have the potential to cause the extensive damage and loss of life that would result in a federal disaster declaration.

Social impacts: Other hazard impacts affected by climate change might not be as devastating to property but could result in death and injury. For example, temperature extremes, both hot and cold, could amplify the risk to transient and elderly populations. From a public safety perspective, OEM is currently more concerned about heat events, as sheltering processes are already in place for extreme cold events. Chapter 5 explores the social impacts in additional detail. Another potential indirect impact of climate change could be an influx of people from other parts of the United States, particularly coastal areas, which are faced with increasing temperatures and sea level rise impacts. The temperate climate and higher elevations of Colorado and Boulder County might become more desirable to those looking to escape hotter temperatures and coastal storms. As an example, Colorado and several other states experienced an influx of refugees from Hurricane Katrina in 2005, the result of a single disaster. Population growth and associated development pressure would create a corresponding need for additional emergency response resources among other county and municipal services.

Wildfires: Climate projections summarized in Chapter 2 suggest that temperatures will increase by 2–3°F by 2030, consequently increasing wildfire risk. Wetter winters and drier summers can increase wildfire risk by providing winter and spring moisture to enable early season vegetation growth, which then dries out in the summer under hotter and drier conditions. These factors would likely lead to a longer fire season, lower fuel moisture, and an overall increase in wildfire vulnerability. More wildfires will then lead to more potential for post-fire erosion, debris flows, and flooding. Under the current climate, wildfires can occur any time of year in Colorado, but the highest danger is generally from June through September. Climate change has the potential to expand the wildfire season. According to the draft county Community Wildfire Protection Plan (CWPP), in 2011, Colorado experienced major fires in January and February and a total of 64 fires in March. The CWPP also references statistics from the Colorado State Forest Service that show an increase in the number and size of wildfires over the time period 1960–2009, not including the elevated number of wildfires in 2010 and the beginning of 2011. This could affect the availability of wildland firefighting resources. Federal resources are usually more readily available during summer months under the current climate. More wildfires, and particularly wildfires outside of the normal "fire season" could stretch locally available personnel and equipment resources. Extreme fire weather conditions severely impact the ability of firefighters to protect property. The focus of firefighters under these conditions becomes getting people out of harm's way and not endangering themselves. In addition, increased wildfires could lead to watershed degradation and drinking water quality concerns, which are discussed further in Chapter 5.

The implications of climate change on certain hazards crosses over into other focus areas within this plan and are not repeated here. Additional impacts of climate change on wildfires and related forest health issues associated with pest and disease outbreaks are discussed in Chapter 6. Extreme temperatures as well as the health-related aspects of wildfires, floods, droughts, and vector-borne illness are examined in greater detail in Chapter 5. Drought and wildfire impacts as they relate to water supply and water infrastructure are discussed in Chapter 3. Refer to those chapters for additional detail. Additional concerns about flood impacts and climate change are discussed further in Section 2.

4.1.2 The effects of climate change on emergency management objectives

The above section focused on some of the general impacts of climate change on hazards that could be observed in Boulder County. In this section we focus our analysis on the specifics of how and why these types of impacts would matter to the agencies that manage hazards in the county, including Boulder OEM, Transportation, Land Use, and the City of Boulder's Utilities Division. The discussion also provides examples of how these entities are currently incorporating planning for uncertainty or extreme events. Highlights of current policies and practices that might be considered part of an adaptive management strategy are also discussed.

OEM

The City of Boulder and Boulder County joint OEM leads a comprehensive EM program as a division of the Boulder County Sheriff's Office. EM is the function that plans, coordinates, and supports a wide range of activities that help communities reduce vulnerability to hazards and prepare for and cope with disasters. OEM's mission is to develop, coordinate, and lead a comprehensive EM program that seeks to enable effective preparation for, efficient response to, and effective recovery from emergencies and disasters in order to save lives, reduce human suffering, protect resources, and develop a more resilient community. Boulder OEM coordinates with state and federal partners, many city and county departments, public safety agencies, municipalities, nongovernmental organizations (NGOs), and private businesses throughout Boulder County in order to facilitate coordinated planning and response to emergency situations.

Guiding documents

Boulder County Multi-Hazard Mitigation Plan (Boulder County, 2008)
Emergency Operations Plan (Boulder County, 2009a)

Climate change will likely underscore the need for and importance of EM and HM in the future. It is likely the current OEM capability will need to expand over time as hazards, exacerbated by climate change, become more frequent and more intense. The Fourmile Canyon wildfire in 2010, along with the resulting post-fire flood and debris flows and ongoing recovery issues, drew significant attention to the critical value of EM and coordination among many Boulder County departments. These hazard events raised the profile of Boulder OEM and engaged several other city and county staff in EM activities.

The Boulder OEM has been a leader in Colorado in many aspects of the field. OEM regularly holds exercises to test plans and procedures with the goal of improving response capabilities. These exercises have included scenarios such as extreme floods. In 2007, OEM coordinated an exercise that tested the county and city's ability to respond to a flood of similar magnitude to the Big Thompson Flood of 1973 coming down Boulder Canyon. This exercise tested the new Emergency Operations Plan, which had been updated and aligned with the National Response Framework to include Emergency Support Functional Annexes.

Recognizing the value of protecting its own facilities from climate hazards, the Boulder Emergency Operations Center (EOC) was relocated in 2009 from a location within the floodplain to a location on higher ground near the county airport. Other enhancements to the EOC have occurred as a result of the move. The county is progressive in its EOC operations and response practices. OEM has four full-time staff dedicated to improving operations plans, continuity of operations/continuity of government plans, hazardous materials preparedness planning, and leadership of the Multi-Agency Coordinating System (MACS) group. OEM has also led the training of Citizens Emergency Response Teams (CERTs) to improve citizen all-hazard preparedness and expand the county's network of trained disaster response volunteers. It is likely the current OEM capability will need to expand over time as hazards, exacerbated by climate change, become more frequent and more intense.

County land use department

Another aspect of HM is avoiding development of hazard-prone areas. This is largely the purview of the Land Use Department that, in consultation with other departments such as Transportation, identifies inappropriate use of flood-prone areas by implementing the county's Land Use Code. The county's Land Use Code is intended to protect and promote the health, safety, and general welfare of the present and future inhabitants of Boulder County and to guide future growth, development, and distribution of land uses within Boulder County. The code defines zoning districts where uses and their intensities are defined. In addition, it establishes the process for subdivisions, site plan review, development standards, and other land use procedures. Among the regulations are several intended to directly mitigate natural hazards impacts to future development or re-development.

Guiding documents

County Comprehensive Plan (Boulder County, 2011a)
County Community Wildfire Protection Plan (Boulder County, 2011b)
County Land Use Code (Boulder County, 2011c)
Fire Management Plan

The county's Land Use Department in partnership with the Sheriff's Office and Parks and Open Space Department is responsible for wildfire mitigation planning. Boulder County government has a long list of accomplishments in community wildfire protection. Wildfire mitigation, awareness, planning, and response efforts, in tandem with forest health initiatives, are considered important aspects of climate change adaptation. A county-wide Boulder CWPP was in development during the drafting of this plan. The draft county CWPP includes a list of significant wildfire mitigation accomplishments since 1993; some of the notable ones include:

- Requiring that a wildfire mitigation plan be approved before issuing a building permit in the mountains since 1993
- Creating its Wildfire Mitigation Coordinator position in 1994
- Beginning its prescribed burning program on Parks and Opens Space property in 1997
- Launching its Forest Health Initiative in 2007
- Completing multiple fuels treatment projects
- Creating the Forest Health Task Force and Forest Education and Outreach Coordinator position in 2008.

In addition to the continued implementation of fuels treatment projects and other initiatives outlined in CWPPs, an increasingly important adaptive management strategy will be reducing the likelihood of wildfire ignitions. An important existing policy intended to reduce the possibility of wildfire ignitions is the authority of the Board of County Commissioners to ban open fires when fire danger is high. In addition to the process to ban open fires, Ordinance No. 2009-1 initiates a process to identify "red flag" fire days; requires notification to Boulder Sheriff's Communications before initiating ditch, field, trash, or slash fire; bans these types of burns on red flag days; and outlines penalties for violation of the ordinance (Boulder County, 2009a). The City of Boulder's Fire Prevention Code [Boulder Revised Code – Title 10-8-2(b.12) adopted 2006] also has provisions for burn bans within the city limits or anywhere on city property outside of the city limits (City of Boulder, 2006).

Boulder County Transportation Department

Boulder County's Transportation Department works to ensure safe and efficient public transportation, both within Boulder County and along regional transportation corridors. Formerly the Public Works Department, the Transportation Department has three main divisions: Engineering, Planning, and Road Maintenance. The department is responsible for implementation of the county's floodplain management program, which is administered by the Planning Division. The Planning Division coordinates closely with the Land Use Department on floodplain determinations and permitting. The department regulates the Floodplain Overlay Zoning District within the unincorporated areas of the county, which is a zone representing the 100-year floodplain. All development and proposed improvements are required to conform to Article 4-400 Floodplain Overlay District of the Boulder County Land Use Code. The department is also responsible for the repair and maintenance of bridges.

Guiding documents

County Land Use Code (Boulder County, 2011c)
Boulder County Comprehensive Plan (Boulder County, 2011a)
Storm Drainage Criteria Manual (Boulder County, 1984)
Transportation Master Plan (2011 draft in development)

City of Boulder Utilities Division

The City of Boulder's Utilities Division of the Department of Public Works is responsible for stormwater and flood management and works to reduce flood hazards, adopt floodplain policies, map floodplains, develop master plans for floodplains, regulate floodplain activities, prepare for flood events, educate the public on floods and floodplains, and mitigate flood potential. The Utilities Division also mitigates the potential loss from floods through the development of flood channels and the installation and maintenance of storm sewers.

The city's local guiding principles for flood management are comprehensive and include:

Preserve floodplains where possible to recognize the beneficial functions of floodplains for hazard reduction, water quality enhancement, wetland protection, wildlife habitat, riparian corridors, recreation, alternate modes of travel, environmental relief, aesthetics, and greenway areas.

Be prepared for floods by developing advanced floodplain mapping, detailed risk assessments, enhanced early warning systems, multiple emergency notification measures, understandable response plans, workable recovery plans, and ongoing storm monitoring.

Help people protect themselves from flood hazards through public interaction and involvement, available flood information, community outreach and education, self-help measures, flood-proofing options, affordable flood insurance, and emergency preparedness.

Prevent adverse impacts and unwise uses in the floodplain through appropriate regulation and land use, open land preservation and acquisition, multi-objective planning, relocation or elimination of high-hazard structures, prohibiting unacceptable encroachments, and establishing ongoing maintenance practices that preserve and enhance environmental functions.

Seek to accommodate floods, not control them through planned and monitored system maintenance, non-structural flood proofing, opening non-containment corridors, overbank land shaping to train flood waters, and limited structural (channelization) measures at constrained locations or where no alternatives are available.

The previous list comes from the city's Comprehensive Flood and Stormwater Utility Master Plan (CFS MP), which contains the guiding principles for flood and stormwater management. Although climate change adaptation is not explicitly stated as an objective of the plan, the guiding principles could be evaluated for inclusion of climate change considerations in future updates.

Guiding documents

Comprehensive Flood and Stormwater Utility Master Plan (City of Boulder, 2004)
City of Boulder Multi-Hazard Mitigation Plan (City of Boulder, 2008)
Boulder County Multi-Hazard Mitigation Plan (Boulder County, 2008)
Individual basin master plans

4.1.3 Anticipated impacts of climate change on floodplain and stormwater management

Climate change could lead to stresses on the county and city's flood and stormwater control infrastructure. Staffing could be strained as well. Much of the county Transportation and Boulder Utilities Floodplain Management staff spend their time preparing for the flood season, which typically begins April 1. Construction projects in floodplains, such as bridge or culvert replacements, typically need to be completed before flood season. The timing of the flood season might be affected by climate change (e.g., earlier peak snowmelt will increase flood risks earlier in the year), which could have a ripple effect on the timing of future planning and on engineering and construction projects and potentially shorten the available window for construction projects. The duration of on-call staffing needs during flood and fire seasons might also expand.

Floodplain management and uncertainty

A significant concern affecting multiple county and city departments is the potential for climate change to affect flood frequency and magnitude. The 100-year flood of today might become a more frequent event in the future (i.e., a 50-year event), meaning that current design levels and regulatory practices might be less adequate in the future. There is no comprehensive assessment of how climate change might affect flooding in the county, but research summarized in Chapter 2 indicates a trend toward less frequent but more intense rain events. In order to consider potential revisions to rainfall-runoff models and corresponding drainage criteria design, the county and city, in coordination with the Urban Drainage and Flood Control District (UDFCD), might want to consider studying the issue in more depth and assessing whether floodplain management practices might need to change in the future.

Certain areas of the City of Boulder's and the Boulder County's floodplain management practices already address uncertainty or extreme events. The City of Boulder and Boulder County both have proactive floodplain management programs. Both entities are members of the National Flood Insurance Program's (NFIP) Community Rating System (CRS), which provides discounts on flood insurance premiums to residents within communities that go above and beyond minimum floodplain management practices. The floodplain management programs are important in reducing, or at least not increasing, the vulnerability of new development or re-development in the regulated floodplains. The regulatory floodplain is the 100-year or 1% annual chance floodplain, which is a nationwide standard, also known as the base flood. The minimum standard is that new development is elevated to the level of that flood. Both the city and county require new development to be elevated 2 feet above the base, or 1% annual chance, flood event. This concept of "freeboard" provides added protection for floods that exceed the base flood. The freeboard requirement could be considered an effective adaptation component, because it allows for protection from more extreme events that could result from climate change. This protection is limited to new construction since 1979, when the county adopted Flood Insurance Rate Maps (FIRMs), joined the NFIP, and began regulating floodplain development. The majority of buildings and other infrastructure in the city and county's floodplains are still pre-FIRM, not elevated, and thus still very much at risk to flooding.

Critical facilities and mobile population ordinance

Although regulation to the 100-year flood is a national standard, the city has long recognized that larger floods can occur. During a January 2002 study session, the City Council endorsed the development of protection measures for critical facilities located in city's floodplains. In 2004, this guidance was incorporated into the city's CFS MP. The CFS MP calls for the development of 500-year protection standards for critical facilities in line with federal guidance to ensure access to, use of, and uninterrupted service for critical facilities such as fire and police stations; water and wastewater treatment facilities; utility infrastructure for water, sewer, gas, electric, and communications; schools; day-care and senior-care facilities; hospitals; major roads and bridges; and hazardous material storage.

The development of a critical facilities ordinance was identified as a mitigation action item as part of the city's Multi-Hazard Mitigation Plan. The plan calls for the adoption of an ordinance that regulates new construction and improvements for critical facilities to the 500-year flood level to protect these facilities from flood losses and damages that could render them unusable during times of need. A draft ordinance has since been developed in 2011 (City of Boulder, 2011a). The ordinance will undergo a public and City Council review and approval process, with a final decision anticipated in spring of 2012.

The City of Boulder, in the process of defining critical facilities, also identified a significant risk to mobile or transient populations in the 100- and 500-year floodplain. People in these groups might not be aware of flood hazards in the city and might not know the appropriate protection strategy of sheltering in place or evacuation. As a result, any mobile population facility, including hotels, motels, dormitories, bed and breakfasts, hostels, and assembly group uses (as defined in the city's adopted version of the International Building Code), shall develop an EM plan for any new construction, development requiring a floodplain development permit, addition of floor area, or substantial improvement requiring a building permit. All mobile population facilities must develop an EM plan during a 10-year implementation window. This requirement ensures that necessary flood education and protection information is available to mobile populations during times of flooding.

The previous examples are ways that regulation can be used to mitigate flood hazard impacts by promoting adaptation to events that exceed the 100-year flood standard. The following is a discussion on opportunities to integrate climate change considerations into department policies, plans, and practices.

4.2 Integrating Adaptation into Emergency Management

Boulder OEM already recognizes climate change as a significant threat, since their mission focuses on managing the consequences of hazards, many of which are driven by climate. Other departments are just beginning to think about the impacts of climate change on their practice areas and are considering adaptation opportunities. Effective climate change adaptation will be best addressed through existing plans, policies, and procedures and not as a stand-alone problem. Opportunities for integrating climate change adaptation into the plans, policies, and procedures of Boulder OEM, City of Boulder Utilities Division, and the Boulder Land Use and Transportation departments have become apparent as a result of this plan's development. As a result of this planning process, four areas have stood out in particular. The first opportunity is integrating climate change considerations into hazards planning. The second opportunity is in the implementation of the mitigation actions identified in the multi-hazard plans, CWPPs, and basin master plans. The third opportunity is broadening HM capabilities, notably for wildfire. Finally, continued collaboration across departments will become even more important as climate change impacts manifest themselves.

4.2.1 Planning

The following specific plans and policies, which drive departmental decisions, have opportunities for integrating adaptation. Many of these plans are updated every three to five years, so there are opportunities to incorporate climate change adaptation considerations in the near future.

Mitigation planning

Both the city and county have separate Multi-Hazard Mitigation Plans,[13] which identify potential hazards, vulnerabilities, and specific goals and actions intended to reduce the impacts of those hazards. By their nature these plans are developed for the purpose of adapting to nature's extremes. They recommend actions that can be implemented in a pre-disaster environment in order to lessen the impact of extreme events. Often there is not funding to accomplish all of the desired projects, and in some cases, mitigation might not happen until damage results and post-disaster funding becomes available. Thus, it will be important to further identify "recovery-mitigation" opportunities and have them outlined for implementation post-disaster. These plans are on a five-year update cycle, with the next updates due in 2013. During the next update, hazards such as extreme heat should be revisited with a climate change perspective and action recommendations related to this hazard should be revisited and possibly reprioritized. Climate change concerns could be included as additional criteria in determining project prioritization. For example, plausible scenarios of climate change appropriate to planning horizons could be included. The city and county evaluated the possibility of combining the two plans in the next update cycle but decided against this due to the volume of information in each plan and the desire to keep jurisdictional specific details within each plan. However, there are benefits from coordinated planning meetings and public outreach activities that could be realized during the next update cycle.

Community Wildfire Protection Plans

The implication of the current science pointing toward hotter and drier conditions in the future raises the importance of CWPP. CWPPs are key in climate change adaptation, even if the topic is not explicitly discussed within them. Defensible space and fuels treatments projects are typical recommendations in these plans, and these projects become even more important with climate change implications. There have been 13 local CWPPs completed between 2005 and 2011. These plans contain a wealth of important information for the communities that they cover (typically fire protection districts) and have resulted in an enormous amount of mitigation work

13. The University of Colorado also has a Multi-Hazard Mitigation Plan, but it is on a different update cycle because it is linked with the State Mitigation Plan. Consequently, we do not explore this plan in great depth here.

by the districts, communities, partners, and individuals involved. During 2011, a county-wide CWPP was developed, which is now required of all counties by state statute. The plan serves as an umbrella document for the local level CWPPs. The plan has the following goals: save lives, protect property, reduce risk, and enhance the environment and promote community. Further implementation of the recommendations of these plans will help simultaneously meet the goals of the plans and build adaptive capacity to climate change.

Recovery planning

Recovery planning often takes a back seat to response and mitigation planning, partly because there are no federal mandates that require recovery plans. The 2010 Fourmile Canyon Fire identified a need for recovery planning in the county. As a result, the county is moving forward on a plan that will be based on experiences from that incident, as opposed to assumptions, with OEM taking the lead on the effort. Climate change is likely to result in more frequent and larger hazard events, thus recovery planning will also likely grow in importance. The current planning effort is looking at a 7- to 10-year planning horizon.

Other plans

Other plans that are in process that will enhance the county's post-disaster capabilities include debris management and damage assessment plans. As noted in Chapter 3, there is a need for continued development of response and recovery plans for the City of Boulder and other water utilities to ensure there is a plan for getting clean water to customers as soon as possible in the event a disaster causes a disruption.

The city's CFS MP, which contains the guiding principles for flood and stormwater management, would be an appropriate document in which to integrate climate change considerations in future updates. This plan states that floodplain regulations should periodically be reviewed and updated to reflect changing community needs and ensure that the flood management objectives of reducing or eliminating safety risks, property losses, and environmental damage are achieved. The periodic evaluation of flood management objectives in this plan could include climate change considerations. The intent is to try and update this plan on a five-year cycle. The equivalent document on the county side is the county's Storm Drainage Criteria Manual, which has not been updated since 1984.

4.2.2 Mitigation project implementation

Hazard mitigation is a major component of climate change adaptation. Hazard mitigation projects can include actions that vary from wildfire fuels treatments and stormwater infrastructure improvements to floodplain property acquisition and public information campaigns. There should be a renewed sense of urgency in implementing these projects to offset the potential impacts of climate change. Often the limiting factor hindering implementation is funding. Costs of implementation can vary from relatively low (can be accomplished with existing staff resources) to multi-million dollar infrastructure improvements. Funding opportunities [grants, utility fees, pre- and post-disaster Federal Emergency Management Agency (FEMA) grants] should be continually monitored and applied where applicable and low-cost options should be regularly pursued.

4.2.3 Hazards management capabilities enhancement

Climate change could stretch thin staff resources that are available for HM and response. The primary area where staff resources might initially be needed to help adapt to climate change is wildfire management. According to the draft county CWPP, the county has a large number of staff who are able to devote a portion of their time to wildfire issues (some of which are seasonal, or short-term employees) but lacks full-time, permanent employees dedicated to wildfire mitigation, with the exception of the area of forest health. In order to implement the recommendations contained in the CWPP and reduce the negative impacts of future catastrophic fires, the county might need to add additional capacity, such as a full-time CWPP coordinator. OEM staffing might also need to be supplemented.

4.2.4 Collaboration and coordination

Collaboration among several county departments on emergency, floodplain, and wildfire management issues is already central in every aspect of meeting multiple department objectives. Increased collaboration across county departments might be needed as cross-cutting issues and concerns arise as a result of climate change. Climate preparedness is already recognized as an important issue by the county commissioners, so this should help reinforce the need for continued collaboration on this topic in the future. Because hazards cross jurisdictional boundaries, planning efforts should foster multi-jurisdictional cooperation in the mitigation, response, and recovery from risks associated with hazards. This is already reflected in the county's multi-jurisdictional Multi-Hazard Mitigation Plan, the CWPP, which is a policy endorsed within the county Comprehensive Plan (Natural Hazard Policy 1.06) and institutionalized through regular monthly meetings of the Boulder Multi-Agency Coordinating System (MACS) group. The MACS group is made up of representatives from numerous City of Boulder and Boulder County departments, nonprofit organizations active in disaster, and the private sector. These professionals and subject matter experts become the foundation of the EOC during incidents. Multi-agency collaboration between local, state, and federal government officials might also become increasingly important in the face of climate change. An example is coordinated resource protection efforts in watersheds prone to wildfires to limit impacts to people, property, and watershed health.

4.3 Policy Recommendations

The following policy or programmatic recommendations are suggested with the intent to either improve or continue practices that will enhance adaptation to a changing climate. Recommendations are based on a combination of interviews and planning meetings with county and city staff that took place during this plan's development. These ideas for recommendations have been expanded upon by the consultant team so that the county and city might consider implementing them in the future.

4.3.1 Continue to reduce vulnerability to hazards through implementation of the following mitigation recommendations within Multi-Hazard Mitigation Plans and master plans

The priority hazard reduction actions or projects identified in the following plans should continue to be implemented as resources allow, both in pre- and post-disaster situations:

Boulder County Multi-Hazard Mitigation Plan (Boulder County, 2008)
City of Boulder Multi-Hazard Mitigation Plan (City of Boulder, 2008)
County Community Wildfire Protection Plan (Boulder County, 2011b)
Community Wildfire Protection plans (various)
Basin master plans and Phase A studies (various)
Greenways Master Plan (City of Boulder, 2011b)
Capital Improvement plans

High-priority projects related to flood and wildfire mitigation should be implemented, but others that address hazards such as extreme heat or meet multiple objectives should receive additional consideration. As an example, the City of Boulder's Multi-Hazard Mitigation Plan has a strong linkage to the city's urban forestry program and contains tree planting and maintenance projects that could help reduce the urban heat island effect and decrease runoff in storm events. These types of projects help adapt for potential climate change stressors such as increases in the number and severity of extremely hot days or increases in precipitation during future extreme rainstorms.

4.3.2 Incorporate climate change considerations in next update to the Multi-Hazard Mitigation Plans for the County and City of Boulder

The next update to these plans will begin in 2012. An opportunity exists to incorporate climate change considerations into both plans, particularly in the hazard profiles for wildfire, extreme temperatures, and other weather-influenced hazards. It is recommended that the severity rating of these hazards be re-evaluated in light of climate change. Boulder OEM has suggested using a consequence-based approach, which would evaluate what impacts (social, buildings, infrastructure, etc.) might be exacerbated by climate change, as opposed to a predictive one.

4.3.3 Incorporate "recovery mitigation" considerations in next update to the Multi-Hazard Mitigation Plan

Further enhance the action recommendations in the county's Multi-Hazard Mitigation Plan to identify those projects most likely to be implemented in the wake of a major flood, when post-disaster hazard mitigation grant funding might become available for things such as floodplain property buyouts.

4.3.4 Continue recovery planning effort underway

Many lessons were learned in the wake of the Fourmile Canyon Fire, and one of those lessons was that further post-disaster recovery planning was needed. It is recommended that the county continue the recovery planning effort born from that disaster. The creation of post-disaster recovery plans will help the county be more resilient when faced with unpredictable extreme events.

4.3.5 Continue to enhance flood detection network

Boulder County has an extensive stream flow and rainfall network and was the first area in Colorado to have the Alert System for flood detection. Some tributaries still need gauges. A real-time camera placed at Fourmile Canyon Creek has helped emergency managers monitor flood and debris flow conditions remotely. More back-lit cameras in other areas would help.

4.3.6 Continue Boulder's emergency management efforts for process improvement and self-assessment

Strong EM capabilities are vital to public safety and health, quality of life, and the economic stability of Boulder County under the current climate. Climate change will likely emphasize the need for a strong EM program, and Boulder OEM has already begun process improvements using Six Sigma principles (a model and methodology for total quality management) and a self-assessment through the MACS group. The office has looked at other accreditation programs including the Emergency Management Accreditation Program (EMAP) but has found it to be too cost prohibitive and resource intensive to go through the process. By seeking continued self-assessment and process improvement, Boulder's EM program would continue to demonstrate their commitment to excellence and accountability.

4.3.7 Hire a full-time CWPP coordinator

Having a dedicated staff to oversee and coordinate the implementation of recommended projects in the county CWPP and local CWPPs will help reduce the potential impacts of future devastating fires.

4.3.8 Adopt and implement the critical facilities and mobile populations ordinance

It is recommended that this ordinance be adopted to protect critical facilities to the 500-year level, reduce the impacts to hazardous materials facilities, and require preparedness plans for mobile population facilities.

4.3.9 Continue to enhance city and county floodplain management programs through participation in the NFIP's CRS

Participation in the CRS recognizes those communities that go above and beyond implementation of the minimum NFIP standards. CRS reviews floodplain management programs every three years to determine the appropriate CRS class. The CRS classes for local communities are based on 18 creditable activities, organized under four categories: public information, mapping and regulations, flood damage reduction, and flood preparedness. CRS ratings include 10 classes, with a Class 1 being the highest. For CRS participating communities, flood insurance premium rates are discounted in increments of 5%; i.e., a Class 1 community would receive a 45% premium discount, while a Class 9 community would receive a 5% discount (a Class 10 is not participating in the CRS and receives no discount). The City of Boulder and Boulder County are both currently a CRS class 7, which provides residents in the floodplain a 15% discount on flood insurance. Improving the rating through other activities would provide greater insurance discounts and more of an incentive for residents to purchase flood insurance. Both entities should explore additional CRS credits that might be available through accounting for climate change impacts.

4.3.10 Evaluate the possibility of including higher regulatory standards for critical facilities protection in the county's floodplain management ordinance.

The current county floodplain ordinance does not have any specific language related to protection of critical facilities. Although few development permits are requested for critical facilities, the county might want to look at the City of Boulder's proposed critical facilities ordinance that specifies 500-year protection for new or substantially improved critical facilities.

4.3.11 Continue to prepare studies that will facilitate rapid recovery from floods and wildfires

Boulder County's Transportation Department has done studies that will help facilitate post-disaster recovery and mitigation. Recognizing that a number of privately owned bridges might need to be replaced to accommodate post-burn debris and flood flows from the Fourmile Canyon Fire, the Department conducted an engineering study so that citizens could be given bridge replacement specifications and not have the burden of conducting their own engineering study. The department has also created a list of major and minor bridges targeted for replacement as well as a flood emergency access map to identify those bridges that would be inundated by a 100-year event. The pre-identification of presently inadequate infrastructure helps to target areas for mitigation. This mitigation can occur pre-disaster and enhance resiliency, as funding and priorities dictate. If the infrastructure is damaged and needs replacement, then mitigation can be incorporated as an aspect of the recovery so that future floods are less damaging. Preparing further studies such as these in advance of an event fosters both mitigation and recovery, in turn, building climate change adaptive capacity.

4.4 Recommendations for Future Study

The following recommendations for future study are primarily based on interviews with county and city staff that took place during the development of this plan. These ideas for recommendations have been expanded upon by the consultant team so that the county and city might consider implementing them in the future. Results of these studies could inform future updates to this plan.

4.4.1 Further research and modeling on economic impacts from disasters

Boulder OEM would like to identify the types of disasters that could potentially cripple the city and county from an economic standpoint. For example, what would the revenue implications be from a 500-year flood in the city? Hazus is a nationally recognized flood loss estimation tool developed by FEMA that could be applied in this research. Hazus has the ability to estimate losses from business disruption, capital and wage losses, and debris generation, in addition to physical damages to buildings and their contents. A Hazus-based loss estimation should be utilized to support long-term recovery, as well as mitigation planning efforts. A level 2 study should be used. Level 2 would enhance and replace Hazus default inventory databases with locally developed GIS data.

4.4.2 Continued research, monitoring, and information gathering on climate change impacts

Continued monitoring and research is needed to better inform this plan in the future. Local monitoring programs can help enhance the understanding of how weather and climate relate to global extremes. It is recommended that the county leverage the resources of nearby research and government institutions including the University of Colorado, NCAR, UCAR, NOAA, and local water resources, climate change, and HM consulting expertise. Of particular interest to the City of Boulder would be the impact of climate change on El Niño/La Niña patterns, as these climate phenomena currently have a significant influence on precipitation patterns in the county.

4.4.3 Continue to update floodplain maps and flood studies

Several areas of the county have recently been re-studied and re-mapped, including South Boulder Creek, Lower Boulder Creek, Fourmile Canyon Creek, and Wonderland Creek in the City of Boulder. Many of the flood hazard maps and studies elsewhere in Boulder County are 20 to 30 years old. These maps need to be updated using modern modeling techniques and high-resolution terrain data that might reflect geomorphic changes to the streams. A new state floodplain rule that will become effective in January 2013 will require communities to use a 6-inch-rise floodway standard, which is more restrictive than the current 1-foot rise that Boulder County regulates to. This will result in an expanded floodway that will need to be phased in with new studies. As recommended in the city's CFS MP, flood studies should ideally be updated every 10 years.

4.4.4 Evaluation of design rainfall in the context of climate change

Flood studies nationwide are typically prepared using hydrology based on historic rainfall and land use conditions. The city bases all flood studies on future land use conditions (full build out conditions), as much of the city is already developed, but design rainfall amounts are based on UDFCD's rainfall criteria. Climate change will affect the frequency and intensity of extreme precipitation events, with analyses to date suggesting that it is more likely than not that the frequency and intensity of extreme precipitation will increase. Although there are few studies that attempt to quantify those changes, it is virtually certain that the uncertainty in estimates of extreme events will reflect the very large uncertainty in estimates of annual and seasonal precipitation in this region. Thus, quantification of the characteristics of extreme precipitation alone will not be a sufficient basis for development of design guidance. Further analysis is required to estimate the degree of conservatism in design standards that minimizes regrets. That is, are the present costs associated with a design standard that proves to be overly conservative less than the present value of future costs due to failure of a design standard that proves to be insufficiently conservative? A somewhat more sophisticated analysis would take into account the evolution of climate and provide for a similar evolution of design standards. Any study should recognize the need for ongoing re-assessment of design standards as our state of knowledge about climate change improves. A study of this type should be coordinated with the UDFCD, and could be designed to be useful throughout the district.

4.4.5 Evaluate the impacts of climate change on transportation infrastructure

The impact of climate change on the transportation sector is recognized by the county as an area for future study. Climate change has the potential to alter freeze-thaw cycles and shrink-swell soils cycles, which could lead to more rapid degradation of road and bridge infrastructure. Regular monitoring of infrastructure and tracking over time might reveal trends, such as more frequent replacement of concrete, which is more susceptible to freeze-thaw cycles. Road maintenance practices such as snow plowing, application of salt/sand, and culvert cleaning might need to be altered. Certain transportation corridors within the county are presently impacted by periodic rockfalls, landslides, and expansive soils. Another area of potential study would be how the potential for these hazards could increase or decrease as a result of climate change.

4.4.6 Inventory, analyze, and quantify urban forest benefits in the City of Boulder

Urban forests provide numerous services related to mitigating climate related hazards, including reduction of stormwater runoff and the urban “heat island” effect, among other benefits related to public health and the absorption of GHG emissions. Trees clean the air, both directly from the absorption of pollutants and by regulating ambient temperatures which minimize ozone formation, and cool buildings reduce air conditioning and thus emissions at the power plant. Urban areas across the country have utilized new science and technology to inventory, analyze, and quantify some of these services using CITYgreen and i-Tree software, to name a few. i-Tree Eco, Streets, and Species are three models to improve understanding, management, and planning by identifying existing structure, function, and value, including selecting tree species and design that maximize specific types of benefits. Armed with this information, policy- and decision-makers can better incorporate urban forest planning proportional to other climate adaptation strategies, and engage multi-scale green infrastructure design through involvement with urban and environmental planners, landscape architects, GIS staff, and forestry/natural resource managers.

4.4.7 Further study of El Niño and La Niña cycles and their implications on Boulder County

El Niño and La Niña cycles currently affect the variability of climate on a year-to-year basis within the county. A better understanding of how climate change may affect these cycles is needed, and what the resulting implications would be in Boulder County. More research from the research institutions based in Boulder would be welcomed. Other areas of study may include the influence of climate change on damaging Chinook winds.

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5. Public Health

Climate change has the potential to significantly affect a wide range of public health stressors in Boulder County. These changes will directly and indirectly affect the ability of BCPH to achieve its mission of protecting, promoting, and enhancing the health and well-being of all people and the environment in the county (BCPH, 2011a). As with other county agencies, BCPH must address the challenges raised by a changing climate across a diverse client population of residents, and visitors, spread over a varying terrain. The resulting variation in the initial vulnerability to specific health outcomes from climate-sensitive stressors is likely to compound these challenges going forward. Further, these challenges must be addressed in an environment where significant operational constraints are largely beyond BCPH's control (e.g., state and federal legislative requirements, available state and federal funding).This chapter examines the potential impacts of climate change on the health of the people living in the City and County of Boulder. As the objective of this plan is to assist county and city departments that manage climate-sensitive resources and assets to achieve their departmental objectives, we look at the challenges climate change might pose to BCPH in the context of pursuing the department's core mission of protecting, promoting, and enhancing personal and environmental health in the county. In this effort, information from existing BCPH documents was supplemented with interviews with BCPH staff in order to ultimately develop a series of policy recommendations and suggest areas for future research to support BCPH's mission.

BCPH is responsible for developing and implementing plans and programs that address a wide range of health stressors over varying time periods within its public health and environmental divisions. Within BCPH, the public health division is responsible for providing services such as vaccinations, communicable disease control, addiction recovery, and community and family health. In contrast, the environmental division is more focused on executing resource-oriented programs, for example, air quality, water quality, and vector control.

In addition to being responsible for addressing long-term public health challenges, BCPH also has a significant support role in coordinating and executing the response to acute public health threats associated with hazards such as floods and wildfires. In responding to more immediate public health threats/emergencies, BCPH does not directly lead the overall response, which is typically coordinated by the county Sheriff's OEM, but generally plays a critical supporting role. For example, BCPH has an emergency mutual aid and assistance agreement with other Colorado public health agencies that authorizes cooperation in disaster prevention, preparedness, response, and recovery. Internally, the BCPH has an Emergency Response Plan that defines teams with roles such as disaster preparedness, communicable disease control, disaster emergency response, and infrastructure.

5.1 Why Consider Climate Change?

As noted above, a wide range of public health issues are affected by climate. For example, air quality has a seasonal trend, in that ground-level ozone is often higher in warmer months because heat and sunlight increase ozone formation, and carbon monoxide is often higher in cold weather because car emission systems are not operating as effectively (U.S. EPA, 2009). This seasonality means air quality is affected by the current climate and is thus likely to be sensitive to future climate change. In this section, we begin by describing some of the potential impacts of climate change on public health relevant to Boulder County. Next, we explore in detail whether and how climate change could affect the management objectives of BCPH and describe some of the specific challenges the department could face under climate change.

5.1.1 Impacts of climate change on public health

It is beyond the scope of this document to provide an exhaustive description of the multitude of impacts that climate change could have on public health in Boulder County. Instead, we highlight key impacts that are likely to affect short- and long-term goals and objectives set by BCPH. The analysis below is based on interviews with BCPH staff as well as scientific literature. It is worth noting that, in many cases, the scientific literature we cite is not focused on BCPH per se, rather we draw on impact studies that address generalized issues relevant to Boulder County. We note where the potential impacts cited have been suggested by interviewees rather than literature.

Extreme temperatures: Among the clearest signals from the existing climate change research is the projected warming in the county over time. As summarized in Chapter 1, this is expected to result in an increase in the following temperature measures:

- Average daily temperatures
- Minimum daily temperatures
- Maximum daily temperatures
- Number of days exceeding “extreme” temperature thresholds (e.g., 100°F).

Collectively, these changes suggest the county should anticipate a significant increase in future extreme heat events. As an example of current conditions, temperature data for Boulder from NOAA ESRL/PSD show that there were 8 days between January 1, 2000 and November 1, 2011 where the maximum daily temperature reached or exceeded 100°F. In this same timeframe, there were 88 days where the temperature exceeded 95°F. These data are presented as a rough baseline of the number of high temperature days the City of Boulder currently experiences.

This change is particularly noteworthy because, although extreme heat clearly has the potential to increase daily morbidity and mortality (Ebi et al., 2006; U.S. EPA, 2006), it is not given much attention or consideration in the county, or within the Front Range region for that matter. This lack of attention is currently reinforced/supported by some of the limited studies that have systematically evaluated the mortality risks of extreme heat conditions in U.S. cities. For example, Medina-Ramon and Schwartz (2007) excluded Boulder when developing extreme heat mortality functions because the authors' minimum temperature criteria were not satisfied, that is, Boulder's minimum temperatures were too cold. Given that average temperatures across Boulder County are projected to increase, excluding Boulder from extreme heat studies might not be justified in the future.

As Chapter 2 notes, the number of future extreme cold events (e.g., cold air outbreaks) might not change. The number of days that satisfy certain fixed temperature criteria for extreme cold would be expected to decline as a result of the generally anticipated winter warming, but in the western United States the direction and magnitude of these changes is less certain. If the number of extreme cold days declines, a corresponding reduction in mortality attributed to cold could be calculated using available epidemiological information (Medina-Ramon and Schwartz, 2007). However, preliminary work currently being conducted for the U.S. Environmental Protection Agency (EPA) suggests the benefit to mortality of reduced extreme cold days will be negated by anticipated mortality increases from increases in the number, duration, and severity of future extreme heat days.

Air quality: Several aspects of climate change have the potential to degrade air quality and thus negatively impact human health. EPA has assessed available epidemiological studies in order to produce concentration-response functions that are widely used to quantify how changes in ambient ozone and particulate matter concentrations impact both mortality incidence and a range of non-fatal acute and chronic health conditions (e.g., asthma-related emergency room visits, school absence days, chronic bronchitis) (U.S. EPA, 2011). These concentration-response functions specify the significant public health impacts that are possible as a result of changing ambient concentrations of air pollutants.

The pathways through which climate change could contribute to the increased ambient concentrations of these pollutants include:

- ***Hotter, drier summers:*** Hotter summer days are expected to increase the demand for electricity to support cooling (i.e., air conditioning). The increased electrical generation required to meet this demand will, all else being equal, increase power plant emissions of NOx and particulate matter. Not only are these bad for human health in their primary form, but the increased emissions of NOx can react with VOCs and sunlight to produce ground-level ozone, resulting in increased ozone formation and higher concentrations. At the same time, the seasonal increases in temperatures could contribute to a longer ozone season. The exact impacts of climate change on air quality as a result of increased summertime power demand are uncertain and will be sensitive to how the increased demand is met, in terms of the location and type of generating sources used.

- ***Wildfires:*** Climate change is expected to result in more wildfires in the Front Range region, including Boulder County. Smoke, particulate matter, and airborne toxics released during wildfires degrade air quality and have the potential to create dangerous conditions, especially for those with respiratory illnesses such as asthma or chronic bronchitis. Other consequences, like loss of life and property and displaced populations, are discussed in the Chapter 4, Emergency Management.

- ***Pollen:*** Research suggests climate change has affected the timing of the spring pollen season, is contributing to the increased abundance of some airborne pollens, and is likely to affect the distribution of some important sources of airborne allergens (e.g., ragweed) (Ebi et al., 2008). This change in timing, location, and duration of the allergy season has the potential to increase incidences of allergic rhinitis and atopic dermatitis, and exacerbate asthma (Reid and Gamble, 2009).

Water quantity/quality/drought: The main public health impact of climate on the quantity/quality of water is expected to be an increase in the effort required to provide reliable access to potable water and/or the risk of increased contaminant levels in future supplied drinking water. Specific county-based climate-driven challenges in this regard include:

- ***Increased nonpoint source pollutant loadings from stormwater flows:*** Increases in the amount of precipitation realized in extreme events would be expected to increase loadings of a range of pollutants (e.g., oil, grease, sediment, nutrients) to waterways receiving stormwater flows. These loadings could be further increased if climate change increases the duration between precipitation events, both "average" and "extreme," as the pollutant load would build in the receiving drainage basin. In addition, as climate change increases the potential for future wildfires, the resulting potential for increased loading of large debris, sediment, and other contaminants from burned areas to waterways would increase.

- ***Increased septic contamination:*** Potential increases in flood severity could also pose a public health risk by increasing the risk that septic systems become exposed and have their contents leak into floodwaters. Increases in flood severity increase this risk by expanding the reach of floodwaters and increasing the flows experienced in other areas (i.e., the future 100-year flood might cover more area and be more powerful compared to today). In addition, any climate-driven increase in the extent of future flooding increases the potential that systems which are not intended to be located in floodplains (e.g., mounded systems) could come in contact with and release contaminants into floodwaters.

- ***Increased water quality treatment challenges:*** The challenges listed above identify potential climate-driven increases in the contaminant load that future water systems might need to address as a result of changes in exceptional precipitation events. At the same time, if climate change reduces average water flows or volumes in source waters for drinking water, the contaminant concentrations could increase with no change in the initial loading. This could present challenges for the county water treatment systems if concentration-based treatment thresholds are approached/exceeded.

- ***Drought:*** In contrast to the listings above, it is not clear how climate change might affect the volume of precipitation the county receives. There is no general model agreement for impacts on the timing and nature (i.e., snow-rain mix) of precipitation and its associated impacts on factors like groundwater flows and losses to evaporation, among others. This lack of agreement, combined with the nature of precipitation distribution across the county (i.e., snow in some areas, rain in others, or precipitation in some areas and not in others), makes it difficult to draw specific conclusions regarding the change in the risk of drought. However, given the link of increased temperature with increased drought potential, the risk of drought conditions developing in at least parts of the county should be assumed to increase in the future as a result of climate change (e.g., the eastern and lower-elevation portions of the county).

Increased pollution and treatment challenges have the potential to increase the work load of water treatment plants (increased contaminant load/decreased supply) and the laboratory services offered by BCPH (increasing work load as more water quality testing is required/requested around the county). Laboratory services may require more staff support than current levels to meet the increased demand. The climate projection (Chapter 2) and water supply (Chapter 3) chapters provide some information that can be used to assess the potential for the emergence of these challenges as a result of climate change. In general, these chapters conclude that it is likely the county will see an increase in the precipitation associated with extreme events. As a result, climate change should be assumed to increase the future challenge of providing potable drinking water at current quality levels.

Vector-borne illness: Climate change, with its associated impacts on vegetation and average/extreme conditions and events, is likely to affect the habitat suitability for different disease vectors and reservoirs (e.g., mice, birds, mosquitoes, deer, bats) (Ebi et al., 2008). This could result in the introduction of new vector-borne illnesses in the county or increased incidence of already present vector-borne illnesses as a result of changes in animal behavior. Examples of possible changes in vector-borne illnesses that might be attributable to climate change impacts included (identified by staff):

- ***Rabies:*** Potential increases if reservoir species spend less time hibernating and therefore more time interacting with other species. Temperature and seasonal changes could result in the migration of rabies into the county that were not here in the past. For example, terrestrial rabies (carried and transmitted by skunks in Colorado) has not been detected in Boulder County, but potentially could if the carrier species migrates due to climate change.

- ***Plague and tularemia:*** Potential increases if winters become warmer and rainier on average.

- ***Mosquito-borne illnesses:*** Milder weather in the current "cold" seasons and warmer weather in the summer could make the county a more suitable habitat for some mosquito species, increasing the potential for additional cases of some mosquito-borne diseases that are already established in the county (e.g., WNV and Western equine encephalitis). At the same time, increases in the precipitation associated with extreme events could increase the habitat suitable for supporting mosquitoes (e.g., *sp. Aedes*) that have a lifecycle linked with flooding. [Note: *Aedes*-linked diseases, e.g., dengue, are not currently established in Colorado, although a case of dengue was reported in Las Vegas, Nevada, in September 2011 (CDC, 2011).]

Drawing definitive conclusions about changes in public health risk associated with vector-borne illnesses as a result of climate change are complicated by the need to also account for any associated changes in human behavior that would accompany the associated impacts to seasonal conditions and daily weather. For example, increased temperatures could result in more time spent indoors during extreme heat days, which could potentially reduce exposure to disease-carrying vectors.

Immediate threats to mortality/morbidity: Among the health stressors in the county likely to be affected by climate change are several that are realized as discrete weather events (e.g., extreme precipitation/flooding, tornadoes) or events that are strongly influenced by weather (e.g., wildfires). Because these events require immediate, emergency response by the city and county, their potential climate-change driven impacts are discussed in the EM chapter (Chapter 4).

Indirect threats: Where climate change is expected to increase some combination of the frequency, severity, and/or duration of these extreme weather events, the direct increase in the risk to public health in the county is clear. Indirectly, changes in the nature of these events also pose an associated indirect public health risk by increasing the potential that existing notification and response plans and staffing resources could be overwhelmed by a single event with particularly extreme characteristics, by the cumulative burden of multiple events of a given type, or by combinations of events that have not previously been experienced or planned for.

Additional indirect public health risks from changes in the characteristics of events attributable to climate change are addressed in the following subsection on changes in health outcomes.

5.1.2 Additional indirect impacts of climate change on public health outcomes

The health stressors identified in the previous subsection can affect the incidence of an extremely wide range of public health outcomes. EPA has attempted to quantify the impacts by developing concentration-response functions for particulate matter and ground-level ozone. These functions relate concentrations to health outcomes (the responses) that range in severity and duration from a day of mild respiratory-driven activity restriction, to emergency room visits and hospitalizations, to the development of chronic bronchitis or increased daily mortality in a population. Considering the additional health stressors identified in this chapter, this range of potential health outcomes would only expand.

However, climate change- driven changes to the stressors identified in the previous subsection are also likely to adversely impact the public health of county residents and visitors. Most clearly, climate change- driven impacts in the number and severity of severe weather events that present life-threatening conditions or cause considerable damage and disruption could adversely affect county residents' mental health. This conclusion is supported by literature examining increased anxiety and depression following different types of extreme weather events/natural disasters (see Ebi et al., 2008).

Clearly, climate-driven changes in the *potential* for future increases in these events or changes in their characteristics are likely to have mental health impacts among county residents vulnerable to the events. For example, the increasing acreage of trees in mountain regions killed by the pine beetle has likely increased anxiety among county residents about the potential for and conditions that could be associated with future county wildfires in forested areas. Similarly, increasing anxiety about drought could have mental health impacts on county farmers and ranchers who rely on relatively junior water rights.

The potential for climate change itself to serve as a direct stressor that could adversely impact mental health is not currently well understood. In 2010, the Environmental Health Perspectives and the National Institute of Environmental Health Sciences published a comprehensive report on public health and climate change, including a chapter on mental health and associated disorders (EHP and NIEH, 2010). The report states, "Psychological impacts of climate change, ranging from mild stress responses to chronic stress or other mental health disorders, are generally indirect and have only recently been considered among the collection of health impacts of climate change" (EHP and NIEH, 2010). However, this line of research is still new. To support work in this area, the National Institutes of Health (NIH) awarded grants for research of mental health and climate change in 2010. Results of this research are not yet available.

5.1.3 The effects of climate change on public health objectives

The above section focused on some of the general impacts of climate change on public health that could be observed in Boulder County. Recognizing that climate change typically might not be an issue of central concern for BCPH, this section discusses whether and how climate change impacts on public health could affect the department's ability to meet its articulated objectives: promoting the health and well-being of the people and environment in Boulder County.

The BCPH's mission statement (BCPH, 2011a) identifies strategic goals, some of which are reproduced in Box 5.1.

Box 5.1. Selected strategic goals, BCPH mission statement

- Ensure that Boulder County residents are empowered to make informed decisions and adopt behaviors that protect and enhance the health of individuals, families, communities, and the environment
- Enhance/initiate/promote services to underserved populations to secure health equity
- Initiate/strengthen partnerships and engage community members in the work of public health
- Incorporate evidence-based, state-of-the-art health practices in policies, programs, and services
- Optimize the use of technology.

These goals define *how* BCPH attempts to execute specific tasks or considerations it will make in developing and executing programs.

BCPH has also identified three focus areas where it will prioritize efforts to realize health improvements over the next five years (BCPH, 2011b). These areas are:

- Mental health
- Obesity (healthy eating and physical activity)
- Substance abuse.

In addition to formally prioritizing areas for health improvement, the 2008 Colorado Public Health Act (SB 08-194) requires county public health departments to:

- Conduct assessments of community health status and the public health system
- Prepare a county public health plan on the basis of these assessments
- Ensure a core set of public health services are provided equitably
- Ensure processes are collaborative, consistent with state plans, and in alignment with resources.

Collectively, these goals, priority areas, and required tasks help define specific health outcome areas where BCPH is looking to achieve improvements while identifying how it intends to make progress in those areas. These elements are critical because they help define current constraints and opportunities BCPH will need to address in developing responses to the challenges of climate change. These issues are addressed further in Sections 5.3 through 5.4.

This focus on agency objectives provides an appropriate frame for identifying climate change-related issues that are likely to be most significant for public health in Boulder County. One important guiding principle in judging significance is whether a particular objective is sensitive to climatic changes. In the case of BCPH's stated objectives, however, many are not thus sensitive. Nevertheless, there are several objectives where climate change is likely directly relevant, and these are described below.

Enhance/initiate/promote services to underserved populations to secure health equity: Underserved and vulnerable populations have a proportionally higher risk to impacts from climate change. BCPH staff have indicated they are concerned about the possibility for extreme heat events to impact sensitive populations within the county. This objective in the BCPH mission statement is relevant to the climate change stressors described in Section 5.1.1, particularly extreme heat events and air quality impacts.

Mental health: Mental health improvements might be challenged by potential increases in the frequency, duration, and severity of extreme weather events or events strongly influenced by weather with conditions that are potentially life threatening or can significantly damage/disrupt the environment and existing infrastructure (e.g., floods, wildfires).

Obesity reduction: Goals of increasing physical activity to combat obesity in the county could be challenged by climate-change-driven degradations in air quality or increasingly frequent conditions that restrict outdoor activity (e.g., extremely hot days). However, warmer weather during currently cold months could expand the active outdoor season.

Reducing substance abuse: Clear links have been established between substance abuse and anxiety and depression. Some concern was expressed that the mental health of county residents could be challenged by climate change, leading to possible increases in substance abuse. As far as we know, however, there is no clear link between climate change and substance abuse.

5.2 Opportunities to Address Climate Change

County public health officials operate in an environment where the goals and objectives at most points in time are likely to be well defined by the state and federal requirements regarding clean air and water, and are reflected locally through BCPH's objectives and commitments. Other focus areas for health improvement are identified through the response to the 2008 Colorado Public Health Act. In this environment, the most effective way to integrate climate change adaptation into public health planning will likely be to link climate change impacts to existing programs, objectives, and mandates. In other words, incorporating climate change objectives into individual programs should be done in a flexible manner to allow the BCPH to most effectively meet regulatory requirements, which likely will not change with future climatic stressors.

5.2.1 Prepare for increased stress on existing programs

Existing programs might need to become more efficient to maintain their current level of success under future climatic stressors. For example, Boulder County is part of the nine-county North Front Range and Denver Metro area that exceeds the EPA ambient air quality standards for ozone (BCPH, 2010). Because climate change will likely increase the potential for elevated ambient ozone concentrations, BCPH will likely need to expend more time and money in the future to avoid the monetary and health-related costs of being out-of-compliance with ozone attainment. Existing county programs will need to become more effective as a result of climate change just to prevent a further elevation in ambient ozone concentrations. Alternatively, ambient ozone concentrations in the area could increase solely as a result of climate change, which could appear to undo some of the program's prior benefits in the public's eye.[14]

5.2.2 Link existing objectives and planning efforts to climate change

Opportunities to draw links between existing objectives and planning efforts and climate change impacts appear to exist at multiple levels. For example, the three focus areas identified by BCPH through its response to the 2008 Colorado Public Health Act clearly could be adversely affected by climate change, as noted in Section 5.1.3.

From a review of relevant BCPH documents, it appears the department's Operational Plan (Ops Plan), which is updated annually, would provide a strong platform for integrating climate change adaptation into public health planning efforts. Specifically, by integrating potential climate change impacts into specific stressors that are addressed as part of the assumptions for individual BCPH programs, the Ops Plan would be effectively moving programs to consider appropriate climate change adaptations. For example, the Vector Control Program within the Ops Plan currently assumes that WNV will exist in the county at levels below what was seen in 2003. Climate change adaptation could be incorporated into this program with a consideration of how suitability of habitats and

14. This interpretation would be largely incorrect. Past improvements achieved by the program would still be helping to avoid even higher ozone concentrations as a result of climate change.

activity supporting the transmission of WNV could be affected through climate change impacts. This adaptation would be relevant for other vector-borne illnesses as well.

The periodic review and updating of BCPH planning documents such as the Ops Plan or the Public Health Improvement Plan provide the opportunity to address climate change adaptation through impacts/challenges to existing programs and objectives.

5.3 Policy Recommendations

Climate change-driven policy recommendations for BCPH are based largely on a consideration of potential climate change impacts in the county, discussions with BCPH staff in phone and in-person interviews, and discussions during climate adaptation committee meetings.

Underlying these recommendations is a general recognition that, in most cases, BCPH has an established history of addressing the general stressors and health outcomes most likely to be affected by climate change, with the notable exception of future extreme heat events. This means, in most cases, that new programs are not needed, or warranted, compared to increasing the opportunities for and effectiveness of addressing climate change impacts through existing programs and objectives. In other words, although programs and objectives might need to shift over time to reflect changing conditions, BCPH likely won’t have to start from scratch to address the impacts of climate change. The recommendations presented below are intended as immediate action items that can help prepare BCPH for climate change.

5.3.1 Develop a comprehensive county recovery plan

One document BCPH staff noted as currently absent from the county’s planning scheme is a comprehensive disaster recovery plan. This plan would provide a protocol for recovering from future large-scale disasters such as the Fourmile Canyon wildfire in September 2010. Development of such a plan would be increasingly warranted with the consideration/recognition that climate change might increase the likelihood that the county could experience such a disaster in the future. Although the Boulder OEM is currently leading a recovery planning effort, the clear potential for such an event to adversely impact short-term and longer-term public health through a number of stressors would warrant the active involvement of BCPH in the plan’s development.

5.3.2 Advocate for consideration of public health impacts in other climate change related decision-making arenas

Discussions with BCPH staff noted that much county decision-making, as with most organizations, is performed within a more immediate time horizon and focus on annual or short-term versus a long range consideration of goals and potential impacts. As a result, there is the potential that, in some cases, different choices would be made if future public health considerations could be incorporated into the decision-making process.

For example, a consideration of the public health impacts in building codes could increase consideration of whether incentives/requirements for increased tree planting or use of alternative roofing and paving materials might be warranted. Having public health officials involved in such decisions could incorporate discussions of how these alternatives could help mitigate urban heat islands or decrease runoff in storm events. In turn, officials could adapt for potential climate change stressors such as increases in the number and severity of extremely hot days or increases in precipitation during future extreme rainstorms.

5.3.3 Enhance community public health partnerships

Part of BCPH's mission statement identifies initiating and strengthening partnerships to enhance public health (see Section 5.1.3). Establishing such partnerships will be increasingly important to reach population groups to which the BCPH does not already have effective access but that might be at elevated risk for specific climate change impacts (e.g., elderly people with limited mobility who lack air conditioning and would be vulnerable during an extreme heat event).

BCPH currently has partnerships with health providers throughout Boulder County, giving the department access to general information regarding incidences of vector-borne disease and substance abuse, to name a few outcomes that would warrant tracking for emergence of a climate change signal. Because climate change affects the nature of specific public health stressors, existing partnerships might need to be enhanced in order to ensure timely and accurate delivery of time-sensitive information or requests for assistance as well as targeted public education efforts. In particular, establishing and strengthening partnerships with groups that have specific expertise providing services to highly vulnerable populations (e.g., the homeless) or groups that are difficult to access through traditional media (e.g., non-English speaking groups, ethnic communities) might become increasingly important.

5.3.4 Encourage viewing climate change in terms of specific challenges and impacts

The public health impacts of climate change in the county will largely be realized through specific health stressors or changes in specific types of health outcomes. Promoting this view might help clarify potential climate-change-driven health impacts on a level where existing county health programs and objectives can reasonably be used to address climate change adaptation. This focus might also improve the public's understanding of what some of the consequences of climate change might be outside of some general increase in global temperatures and increase their desire for and acceptance of efforts to plan and mitigate for future changes.

5.4 Recommendations for Future Study

Many ideas and suggestions were developed during the course of our research. Interviewees and expert reviewers suggested many more. The recommendations for future study that are presented below focus on topics where BCPH currently does not have dedicated programs in place and where there are potentially high consequences for significant health impacts that can be strongly associated with climate change.

5.4.1 Extreme heat impacts and extreme heat program needs assessment

The county currently lacks a coordinated extreme heat notification and response program. Pursuing this recommendation is warranted based on past experience and current typical county weather conditions. However, climate change projections suggest extreme heat days are likely to increase in the future.

Research that integrates existing epidemiological results could be integrated with climate projections and possible heat-mortality response functions to quantify potential future health risks from these events at different time periods and under different scenarios. Such integration could help with decisions about if, when, and how to move forward with developing a heat event program. This effort could also include research to identify and adapt potentially relevant existing heat program materials, including a review of potentially relevant best management practices in existing programs and suggestions for critical partners to approach about developing program elements.

As part of developing a comprehensive notification and response program, research could be undertaken to help BCPH establish "heat threshold conditions." These thresholds would represent the weather conditions that, when either met or forecast, would allow BCPH to inform the public of the risk and activate program response elements (e.g., monitor vulnerable populations and provide transportation and access to community cooling centers). This research could likely build on the county's experience in planning and responding to severe cold events and associated sheltering protocols.

5.4.2 Qualitative ranking of potential new health stressors attributable to climate change

Completing a qualitative ranking of the potential scope and severity of public health impacts from the range of new climate-sensitive health stressors would help BCPH prioritize areas for additional climate change research. Such a ranking would draw on the knowledge of BCPH staff and potentially others, such as critical program partners, to help identify climate-sensitive pathways where potentially significant public health impacts exist.

5.4.3 Evaluate results of research from NIH mental health grants and/or other areas of climate change impacts to mental health study

Because mental health is one of BCPH's three focus areas for improvement in the county, it is recommended that the results of emerging research regarding climate change impacts to mental health be evaluated as they are made available. These results would then be used to inform future planning/programs within the mental health focus area.

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6. Agriculture and Natural Resources

Climate change is likely to affect a wide range of attributes of the agricultural and natural resources of Boulder County. For example, climate can affect the availability of water for irrigated agriculture, the frequency and intensity of agricultural and forest pest outbreaks, habitat quality, the health and survival of particular species, the suitability of public lands for recreation, the prevalence of invasive species, and the frequency and intensity of wildfires. This is because critical physical and ecological processes associated with each of these attributes are sensitive to climatic variables, including average, seasonal, and extreme temperatures; precipitation amount and timing; and patterns and intensities of drought.

Both the City of Boulder and Boulder County administer a municipal land management agency. BCPOS has preserved almost 100,000 acres of land for city shaping, habitat conservation, agricultural use, and recreation. Of these, the county owns outright or has some management interest in approximately 64,000 acres (Boulder County, 2011a). The City of Boulder's Open Space and Mountain Parks (OSMP) Department owns or manages approximately 45,000 acres of land for similar purposes. Of these, the city is responsible for the management of some 35,000 acres (staff interview). The remainder are privately held and protected by conservation easements that prohibit further development. Many of these lands are owned in fee interest as government property, but many others are managed under conservation easements that prohibit further development and sometimes restrict use of privately owned land.

BCPOS and OSMP are responsible for managing a variety of activities on these lands, many of which will be sensitive to climatic changes, including irrigated crop agriculture, species and habitat conservation, human use and recreation, invasive weed management, and fuels treatment and fire management. The land portfolio of these two agencies is largely, but not entirely, within Boulder County and extends from the high elevation prairie lands in eastern Boulder County to the foothills of central Boulder County; there are limited holdings in the higher elevation portions of western Boulder County.

The remainder of this chapter examines the challenges that climate change might pose to agriculture and public lands management in Boulder County. Although we touch on scientific knowledge of climate change impacts, this chapter is meant primarily for decision support. To that end, we move away from the generalities of what climate change might mean and focus on specific challenges and opportunities in Boulder County and within the institutions of BCPOS and OSMP. Our analysis is based on the peer-reviewed scientific literature, an archive of dozens of plans from both organizations, and interviews with 12 individuals with the city and county open space departments.

6.1 Why Consider Climate Change?

As noted above, key characteristics of agriculture and natural resources are affected by climate. For example, the productivity of agricultural crops, water resource availability, the distribution and abundance of species, the quality and type of recreation that are available to people – all of these are strongly affected by current climate and are thus likely to be sensitive to future climatic change. In this section, we begin by describing some of the potential impacts of climate change on agriculture and natural resources relevant to Boulder County. Next, we explore in detail whether and how climate change could affect the management objectives of BCPOS and OSMP and describe some of the specific management challenges these entities could face under climate change.

6.1.1 Impacts of climate change on agriculture and natural resources

It is beyond the scope of this document to provide an exhaustive description of the multitude of impacts that climate change could have on all agriculture and natural resources found in Boulder County. Instead, we highlight here key impacts that are likely to affect resources managed in whole or in part by the public sector. Our analysis is based on interviews with 12 staff from city and county open space departments as well as peer-reviewed literature. It is worth noting that, in many cases, the scientific literature we cite is not focused on Boulder County ecosystems, species, or resources per se. Rather, we draw on impact studies that address generalized issues that are relevant to Boulder County. We note where the potential impacts cited have been suggested by interviewees rather than peer-reviewed studies.

Agricultural productivity and management: Climate change can have varying impacts on agriculture, depending on crop type and location. Higher CO_2 levels generally tend to cause plants to grow larger and become more water efficient. However, for crops already near their maximum heat tolerance, yields might decline or more irrigation might be necessary to reduce heat stress by creating a cooling effect in the near-plant microclimate. Because of a reduction in the time between when the seed grows and the plant matures, a number of crops, including wheat and corn, might show decreasing yields with increasing temperatures. In general, optimum temperatures for reproductive growth are lower than those for vegetative growth, meaning that increased early-season temperatures might shorten crop life cycles and make plants less productive overall. Increased temperatures beyond the optimal range of 77–95°F during the grain filling period are expected to reduce yields, although irrigation is often used to lower ambient temperatures. Corn also experiences reduced yields if temperatures during the reproductive phase dramatically exceed 86°F. Weeds, on the other hand, are expected to benefit from rising CO_2 levels and rising temperatures (CCSP, 2008). Finally, although warmer temperatures generally translate into an increase in GDDs and a longer growing season, an earlier start to the growing season might leave plants more vulnerable to late frosts (Inouye, 2008; USGCRP, 2009).

Grazing: Rising temperatures might increase the length of forage production seasons but reduce forage quality, leading to a net increase in area needed to accommodate grazing animals (USGCRP, 2009). Note also that high atmospheric CO_2 levels decreases the nutritional quality of plants. Lengthening growing seasons, however, could reduce the need to accumulate winter forage. These impacts are dependent on water availability, which could be reduced under climate change, particularly in the late summer (CCSP, 2008).

Local species extinctions: Changes in temperature and precipitation patterns and extremes can lead to the local extinction of species if key physiological thresholds are exceeded. For example, the breeding success of the northern leopard frog declines in dry years (staff interview). Extended periods of drought could lead to the local extirpation of this species. Similarly, cold-water fisheries, such as cutthroat trout, suffer higher mortality during the low flows associated with dry years because water temperatures can increase beyond acceptable thresholds (staff interview). Again, persistent or extreme periods of low flows might lead to the local loss of this species. Other plant and animal species might also suffer as temperature, precipitation, and disturbance regimes shift in the future.

Species range shifts: In response to warming, many species are expected to shift their ranges northward and upward in elevation. Range shifts to higher latitudes have occurred for species from all well-studied plant and animal groups on all continents (Parmesan, 2006; Rosenzweig et al., 2007). On average, species in the Northern Hemisphere have moved 6.1 km per decade (Parmesan and Yohe, 2003). Contractions of species ranges have been observed for some range-restricted species, such as those found at the tops of mountains (Parmesan, 2006). These range shifts have been attributed to recent changes in climate by statistical analyses that demonstrate that they are (1) consistent with the expected responses to documented changes in climate; (2) unlikely to be entirely due to natural variability; and (3) inconsistent with alternative, plausible explanations that exclude changes in climate (Rosenzweig et al., 2008).

Changes in phenology: Climate change is likely to alter the timing of key events in species or ecosystems. For example, recent observations show that spring is arriving earlier on most continents and for species occurring in well-studied marine, freshwater, and terrestrial groups (Parmesan, 2006; Rosenzweig et al., 2007). Quantitative analyses suggest the advance arrival of spring from 2.3–5.2 days per decade across species over the last 30 years (Parmesan and Yohe, 2003; Rosenzweig et al., 2007). Changes include earlier bud burst, flowering, emergence from hibernation, migration, and breeding. When these phenological changes affect co-occurring species, they can disrupt species interactions, including predator-prey and plant-pollinator relationships (Rosenzweig et al., 2007).

Extended dry seasons due to earlier snowmelt: Snow reflects a large portion of incoming solar radiation, and a reduction in the duration of snow cover therefore will allow for more pronounced soil warming during the warm spring and summer months (Armstrong and Brun, 2008). Snow also insulates the soil from cold air temperatures during the fall and early winter months and prevents the soil moisture from evaporating. The combined effects of later snow accumulation and earlier snowmelt results in a longer growing season for vegetation with the potential for prolonged dry seasons and droughts. This observed trend is projected to continue and become more pronounced throughout the 21st century (Mote et al., 2005; Stewart et al., 2005; Lemke et al., 2007; Bates et al., 2008; Lettenmaier et al., 2008). A longer snow-free season that decreases soil moisture can exacerbate the impacts of drought caused by reductions in precipitation, potentially increasing risks of wildfire and pest outbreaks (Westerling et al., 2006; Raffa et al., 2008).

Pest and disease outbreaks: A combination of factors can contribute to increases in pest outbreaks under climate change. Higher temperatures can contribute to increased survival and productivity of pests (Logan and Powell, 2009). In addition, drought and heat stress caused by climate change can make forests more vulnerable to insect outbreaks (Colorado Division of Forestry, 2004). For example, in recent years, pine forests in the Rocky Mountains of the western United States and British Columbia have experienced widespread outbreaks of mountain pine beetles that can kill or damage trees. Because dead trees ignite more readily than living trees, some researchers have suggested that large-scale pest outbreaks may increase wildfire risk (Kurz et al., 2008); however, this theory remains controversial.

Wildfires: Seasonality of average and extreme temperatures and precipitation has a significant impact on wildfire timing, frequency, and magnitude. For example, early vegetation growth due to a wet spring can lead to rapid fuels build-up that increases risk of fire as that vegetation dries out over the summer (staff interview). Similarly, earlier snowmelt, which extends the fire season, has increased fire frequency and intensity in the western United States (Westerling et al., 2006). Extreme hot and dry conditions can significantly increase wildfire risk at any time of the year. If climate change leads to warming, as anticipated, and to possibly drier conditions, this could affect the severity and frequency of wildfires, requiring alterations in fuels treatments and fire management practices.

Invasive weeds: As with any other plant species, weeds are likely to be affected by climate change. It is difficult to predict whether any given invasive species will do better or worse under elevated CO_2 and climate change, but invasive species dynamics could change significantly. For example, warm season grasses (C_4) are expected to respond favorably to warmer temperatures under water-limited conditions, but cool season (C_3) grasses generally respond more favorably to higher atmospheric CO_2 concentrations (Morgan et al., 2011). The impact of climate change on the rate of expansion of any given species will be highly dependent on local water and nutrient availability, the species intrinsic growth rate, local disturbance regimes, and the species with which the species is competing. However, some general issues might arise under climate change. For example, pesticide application might need to be delayed because of an unusually wet spring. This is because of concerns about pesticide application vehicles physically accessing crops on wet fields and because of concerns about non-point source pesticide contamination of water resources (staff interview). Because pesticides are more effective on smaller plants, this delay could reduce the effectiveness of weed control efforts. Also, earlier springs might require that weed management activities begin earlier in the year.

Changes in wetlands: Freshwater wetlands are likely to be affected by changes in precipitation and temperature (Burkett and Kusler, 2000). Decreases in precipitation or changes in precipitation timing, especially in combination with increased evaporation from higher temperatures, can shrink wetland area or change the species composition of a wetland (Kling et al., 2003).

Plant growth: It is unclear how climate change will affect plant ecosystems in Boulder County. Some forest tree growth might be stimulated by increased concentrations of CO_2 and longer growing seasons. However, most of that growth will be in young trees with sufficient water and nutrient availability. Wildfire disturbance regimes are likely to place important constraints on plant productivity and growth, as will dry season length and intensity. The specific impacts of climate change on the productivity and composition of specific ecosystems remain to be seen.

6.1.2 The effects of climate change on agriculture and natural resource objectives

The above section focused on some of the general impacts of climate change on agriculture and natural resources that could be observed in Boulder County. In this section, we focus our analysis on how and why these types of impacts would matter to BCPOS and OSMP, which are responsible for managing natural resources in the county. We recognize that climate change is not typically an issue of central concern for BCPOS and OSMP. However, in this section we discuss whether and how climate change impacts on the natural resources of Boulder County could affect the departments' ability to meet their articulated objectives.

The City of Boulder's OSMP Department's objectives are defined by Article XII of the City Charter and reproduced in Box 6.1 (Colorado Code Publishing Company, 2007).

The stated mission of BCPOS is "To conserve natural, cultural and agricultural resources and provide public uses that reflect sound resource management and community values." The specific goals of BCPOS are listed in Box 6.2 (Boulder County, 2011b).

Box 6.1. City of Boulder OSMP Department's formal objectives

Open space land shall be acquired, maintained, preserved, retained, and used only for the following purposes:

1. Preservation or restoration of natural areas characterized by or including terrain, geologic formations, flora, or fauna that are unusual, spectacular, historically important, scientifically valuable, or unique, or that represent outstanding or rare examples of native species
2. Preservation of water resources in their natural or traditional state, scenic areas or vistas, wildlife habitats, or fragile ecosystems
3. Preservation of land for passive recreational use, such as hiking, photography, or nature studies, and, if specifically designated, bicycling, horseback riding, or fishing
4. Preservation of agricultural uses and land suitable for agricultural production
5. Utilization of land for shaping the development of the city, limiting urban sprawl, and disciplining growth
6. Utilization of non-urban land for spatial definition of urban areas
7. Utilization of land to prevent encroachment on floodplains
8. Preservation of land for its aesthetic or passive recreational value and its contribution to the quality of life of the community.

Box 6.2. BCPOS Department's formal objectives

1. To preserve rural lands and buffers
2. To preserve and restore natural resources for the benefit of the environment and the public
3. To provide public outreach, partnerships and volunteer opportunities to increase awareness and appreciation of Boulder County's open space
4. To protect, restore and interpret cultural resources for the education and enjoyment of current and future generations
5. To provide quality recreational experiences while protecting open space resources
6. To promote and provide for sustainable agriculture in Boulder County for the natural, cultural and economic values it provides
7. To develop human resources potential, employ sustainable and sound business practices, and pursue technological advancements.

We focus our analysis on agency objectives to provide an appropriate frame for identifying climate change – related issues that are likely to be most significant for natural resource management in Boulder County. One important guiding principle in judging significance begins with whether a particular objective is sensitive to climatic changes. For example, the productivity and viability of agriculture is currently affected by extreme temperatures, drought, too much or too little precipitation, and irrigation water availability. The sensitivity of agriculture to climate indicates that agriculture is highly likely to be affected by climate change. Below, we describe the likely relevance of climate change to specific BCPOS and OSMP objectives, moving in general from the most to least sensitive to climate change.

Preservation of water resources: BCPOS and OSMP manage a number of lakes, ponds, creeks, and wetlands as well as water for irrigated agriculture. Water resources are sensitive to average, seasonal, and extreme precipitation; snowmelt timing; average and extreme temperatures; and cycles of drought. Current climate variability affects the volume of water available for agriculture as well as the quality of aquatic, wetland, and riparian habitat. In the future, earlier snowmelt, lower summertime precipitation, and higher summertime temperatures could combine to increase water scarcity in the late summer and reduce wetland quality and area.

Ecosystem preservation: Species and habitats respond directly to changes in the magnitude, frequency, and seasonality of temperature and precipitation regimes as well as indirectly to competition from invasive weeds, changes in wildfire frequency and severity, and similar impacts. As noted earlier, climate change might have a number of effects on native ecosystems, including (1) local extinctions of species as altered climatologic conditions move beyond specific thresholds of physiological tolerance; (2) geographic shifts in key species of interest (e.g., shifts upward in elevation) that move them outside of the jurisdictional boundaries of the management; (3) increases in outbreaks of pests that degrade forest habitat and/or make them more vulnerable to wildfire; and (4) changes in the timing of important life stages or events (e.g., flowering, migration, breeding) that, when affecting co-occurring species, has the potential to disrupt predator-prey and plant-pollinator relationships. Given the sensitivity of ecosystem dynamics to climate change, efforts to conserve ecosystems will likely have to adapt to changing species dynamics under a future climate.

Promote sustainable agriculture: Agriculture is sensitive to changes in temperature, precipitation patterns, water availability, and pest and disease incidence. This objective is also affected by the availability of water resources, which is also affected by climate. Maintaining agricultural productivity under a future climate might require the introduction of new crops or breeds, modified management techniques, and/or increases in irrigation water if less precipitation is available to meet crop needs. Given water might generally be in shorter supply, more efficient methods of applying water might also be required for sustainable agriculture.

Provide quality recreational experiences: Recreation opportunities on open space lands include trail-based recreation, climbing and off-trail travel, parking and picnic facilities, fishing opportunities, wildlife viewing, and more. Some recreational infrastructure and the timing and volume of recreational activity are sensitive to climate. For example, the type of recreational fishing that is available (e.g., warm-water, cool-water, cold-water) is dependent on water temperatures in lakes and streams, and this is sensitive to climatic conditions. In addition, people are more likely to fish and hike on sunny, warm days; temperature and precipitation thus also affect recreational patterns. If the type, total, and/or temporal and spatial distribution of recreational trips change over time, management strategies might need to change in response.

Protection of cultural resources: Cultural resources managed by these agencies include Native American archeological sites as well as historic mines, ranch houses, and farmhouses. These resources have some minor sensitivity to climate, including risk to flooding along waterways and fire risk to historic structures as well as wear and tear to the structures themselves from extreme heat, cold, and precipitation. Because the sensitivity of cultural resources to current climate is low, we anticipate their vulnerability to climate change to be low as well.

Public outreach, partnerships, and volunteer opportunities: Although public outreach might be helpful in educating the public about climate change, these procedural objectives are not sensitive to current climate and thus unlikely to be affected significantly by climate change. Nevertheless, if climate change leads to observable changes in natural ecosystems, agriculture, or other aspects of our public lands, it might spur more people to learn about their public lands and the impacts that they have observed. Observed impacts of climate change might also present opportunities to educate the public about climate change and its consequences. To be sure attribution of climate change at a local scale is very challenging, but education can identify the types of changes that we expect to happen.

Develop human resources, sustainable business practices, and technology: Although climate change might affect some business practices and human and technological resources, these procedural objectives are not sensitive to current climate and thus unlikely to be affected significantly by climate change.

Preservation of rural lands and city shaping: This objective is a function of acquiring the land to legally prevent further development. Climate plays very little role in accomplishing this objective, and this objective is unlikely to be affected by climate change. Note that this does not mean that the use of rural lands is not sensitive to climate change but simply the prevention of urban development.

Preservation of aesthetic values: This objective is often conceived as a function of acquiring the land to legally prevent further development – development being the activity that would detract from the aesthetic value of the land. Climate plays very little role in accomplishing this objective, and this objective in unlikely to be affected by climate change. However, the effects of weather and climate such as increased fire incidence, widespread vegetation die-offs due to the pine bark beetle or other forests pests, changing vegetation regimes, and other potential climate-related impacts might affect the aesthetic value of land that has already been preserved.

6.1.3 Key future management challenges for BCPOS and OSMP

In this section, we describe key issues related to managing natural resource management under current and future climates that were emphasized during our interviews with staff from the city and county open space departments. In some cases, interviewees felt the agencies were well positioned to address climate-related challenges; in other cases, staff felt climate change would pose significant challenges.

In several interviews, multiple staff members from both departments felt their organizations have been generally successful in achieving departmental objectives despite the challenges posed by weather and climate. In fact, they felt that they were perhaps well positioned to cope with some of the changes in climate that might be in store. For example, activities within BCPOS and OSMP already utilize adaptive management to deal with existing weather and climate variability, shifts in land use on adjacent properties, increased recreational use, wildfire risk, and other existing management concerns.

However, staff was also concerned about new threats that might occur as the baseline climate shifts to a “new normal.” This is especially the case where such climate changes might affect the survival or existence of a resource being managed (e.g., permanent drying of wetlands, survival of cold-water fisheries). In these cases, the standard management practices in use by the organization (e.g., prescribed burns, specific weed management practices, managing for key species of concern) might no longer be effective. Similarly, certain objectives might cease to remain salient over time (e.g., preservation of the American pika, supporting irrigated agriculture under current water rights).

Several interviewees were also concerned that climate change would exacerbate the already challenging situations where conflict arises between departmental objectives. For example, providing water for irrigated agriculture might come into greater conflict with maintaining high-quality aquatic and riparian habitat. Or the demand for recreation might increase at the same time that species face greater risks to survival due to climate change. Interviewees anticipated that balancing conservation efforts with demand for recreation and agricultural needs will become more challenging in a climate-altered future.

In addition to these general concerns, staff noted the following specific issues that they felt would be challenging to cope with as climate changes:

Water resources: Water was noted as a particularly vulnerable resource. Interviewees noted the high dependence of Front Range water resources on winter snowfall and the timing of snowmelt. As noted earlier in this chapter, drier winters and/or earlier springs can extend the dry season significantly. These dynamics would clearly also affect wetland, riparian, and aquatic habitat. (See Chapter 3 for more on water resources.)

Agriculture: Many interviewees recognized the vulnerability of agriculture to climate change. They noted that crop output is highly vulnerable to the duration and timing of extreme weather events. For example, extreme heat and cold events can cause physical crop damage, and extreme precipitation events can have a variety of impacts on crop health. Depending on when the precipitation occurs, extreme rainfall events can wash away soil, seeds, or plants. Hail can also cause physical damage. Interviewees also noted that when crops are used as livestock feed, weather events can affect livestock production. Seasonal water scarcity was noted as another important threat to crops. Despite these concerns, agriculture has been adapting to these types of challenges for many years, so it might be well suited to adapt to long-term climatic change.

Wildfire: Many interviewees were concerned with potential climate change impacts on wildfire dynamics. They noted the potential for drought and extreme summer heat as factors that would increase fire risk.

Grassland management: Interviewees were concerned about the specific challenges that climate change could pose for grasslands, including changes in the abundance of cool or warm season plants as well as a need for changes in invasive species management strategies and techniques.

Restoration: Restoration efforts were noted as being sensitive to annual weather variation. Interviewees noted that unusual weather patterns might put native plants at a disadvantage, which could slow efforts to eradicate non-natives and establish native plant communities. If climate variability increases, planning for effective restoration would likely be more challenging.

6.2 Opportunities to Address Climate Change

There are a number of opportunities for integrating adaptation to climate change into planning, management, and operations of both BCPOS and OSMP. Three activities stood out in particular as ripe for intervention. The first opportunity is integrating climate change considerations into strategic planning documents. The second opportunity is addressing climate change through the refinement of standard operating procedures of management. The third includes the day-to-day operational decisions made by specific department personnel. A fourth opportunity involves changing the mind-set of natural resources managers such that they recognize that they cannot and should not expect the systems and species that they are managing to remain static – changes are inevitable, and management approaches should be flexible to accommodate them as time evolves.

6.2.1 System-wide strategic planning

Both OSMP and BCPOS generate system-wide strategic planning documents to drive and justify departmental decisions at a meta scale. The most important planning documents mentioned by interviewees in OSMP were the *Grassland Ecosystem Management Plan, Forest Ecosystem Management Plan,* and *Visitor Master Plan*, although specific *Trail Study Area* plans were also mentioned as important. The most important planning documents mentioned by interviewees in BCPOS was the *Boulder County Comprehensive Plan, Forest Management Policy, Grassland Management Plan: Prairie Dog Habitat Element,* and *Noxious Weed Management Plan;* a *Food and Agriculture Plan* is under development, along with plans for water resources, visitor resources, cultural resources, and conservation easements. County staff also indicated that property-specific management plans are important guiding documents.

However, the planning horizon for most of these documents is around 10 years. Generally, changes can be made in between plan updates, but this is not common. Although interviewees suggested that incorporating climate change adaptation into these guiding documents seemed plausible under the right circumstances, it is not clear to us that explicit incorporation is necessary. For most resources that are sensitive to climate conditions, these sensitivities were explicitly discussed in the planning documents along with strategies for mitigating the adverse consequences of unfavorable climate conditions. Because the planning horizon for these documents is only 10 years and significant changes in climate are unlikely in such a short time frame, it is unlikely that actual management changes will be needed more frequently that these plans are revisited. One interviewee observed that these plans typically deal with current issues, without much discussion of the future.

Despite the generally anticipated 10-year planning horizon, sometimes specific plans remain in place for far longer. For example, an upcoming revisit of the Walker Ranch Management Plan by BCPOS will be the first time this plan has been revisited since 1985 – more than 26 years. The 10-year planning horizon might be optimistic given the large and increasing number of planning documents in both OSMP and BCPOS. Given this reality, there might be a reason to explicitly incorporate climate change considerations in some aspects of system-wide plans. One way to accomplish this without detracting from the important work of plan development is to explicitly call out vulnerabilities to climate variability or change in planning documents and recommend adaptive management to cope with unrealized potential impacts.

The major exception to this rule appears to be monitoring regimes. Many of the system-wide management plans have set up environmental monitoring regimes to observe change in variables of interest over time. Although many of these monitoring regimes collect climate data, some do not. The causal link between ecosystem changes and climate change might be difficult to establish in the non-linear, stochastic, and sometimes chaotic relationship between species, ecosystems, climate stressors, human stressors, etc. Nevertheless, monitoring programs with the ability to capture climatic information have established a baseline of data for future analysis that might prove invaluable. Because many monitoring regimes are already being established, it makes sense to ensure that they collect climate data as well. Such monitoring programs will allow departments to better understand how climate change is affecting natural resources and thus how best to adapt their management strategies as the systems they manage change.

6.2.2 Management policies and standard operating procedures

Beyond system-wide strategic plans, there are often sets of standard operating procedures spelled out in management documents or "policies." For example, BCPOS has a "Weed Management – Policies and Procedures" document that complements the *Noxious Weed Plan*. Such documents typically are more easily read and contain specific references to the range of management practices employed by the agency. These policies often include explicit recommendations about when to employ which management strategies as well as legal requirements for management. OSMP often incorporates these operating procedures within their system-wide plans. However, it makes sense to discuss these sections here because they represent a different level of decision-making with consequent differences in whether and how climate change can play a role in management.

Management policies are generally written as guidance documents that provide little context or reasoning behind the recommendations they provide. Instead, they serve as operating manuals to direct the reader on how business is conducted by the agency on the resource under discussion. The policies and standard operating procedures in these documents could sometimes benefit from "asking the climate question." For example, a standard operating procedure for applying herbicides based on specific calendar dates could instead emphasize the time frame after the onset of spring. Such a change could account for shifts in seasons and ensure that pesticides are applied while plants are small and pesticides are most effective.

6.2.3 Operational decision-making

The third level of decision-making is essentially on-the-ground operations or specific prescriptions for management action. The majority of management flexibility occurs at this level. For example, when a conflict exists between the use of water for irrigation and for species habitat during critical periods for reproduction or survival, the potential conflict is often solved with a simple conversation between the resource manager and the farmer. Irrigation timing can often be delayed or modified to ensure that the necessary flows for spawning fish, for example, are maintained.

Similarly, weed management decisions must be made every day based on observed conditions on the ground. If a species of concern is growing faster than anticipated in one location, resources can be moved to ensure that area is treated before the plants bloom and spread their seed. If one management technique that was prescribed, such as mechanical thinning, did not achieve management targets, complementary techniques might be brought to bear, such as pesticide application. Even if some of these decisions are spelled out in the standard operating procedures, variance from those procedures on the ground is inevitable.

Although climate is seldom a consideration in operational decision-making (although weather certainly is), this type of decision can be relevant to adapting to climate change. This is because operational decision-making exemplifies the flexibility and resilience typically sought after in adapting to a changing climate. The ability to manage the system under a variety of on-the-ground conditions is a critical aspect of adaptation, although this must occur over longer time frames for climate change.

Consequently, operational decision-making can be looked to as a laboratory for generating innovations in agriculture and natural resources management that will increase system resilience to changes in climate. Another way to consider this is that we don’t have to know exactly what to do in advance of change if we have developed a culture of active adaptive management. Under these circumstances, we can often delay decisions with uncertain payoffs while we wait for more or better information, with the knowledge that the capacity of the organization to deal with climate change is being developed.

6.2.4 Changing the mind-set of natural resource managers

Many interviewees noted that natural resource management has often been focused on a particular target species within the jurisdictional boundaries of a park. However, given that climate change will likely affect which species persist in different locations, interviewees felt this approach would likely need to change.

The core issue here is that the baseline that resource managers are trying to maintain or restore might change over time as climate changes. In some cases, species might shift entirely out of a given park and entirely new species might shift in. Under the conventional management paradigm, this would represent a management failure. But given climate change, it might be necessary to rethink how success is defined over longer time frames. In Boulder County, some species will move up in elevation to compensate for climate change. Climate change might push other species over a threshold that leads to their ultimate local extirpation. Given this possibility, new definitions might be needed for assessing management success and failure. A flexible baseline might need to be developed that allows for landscape changes due to factors outside of management control that establish new baseline conditions.

Many entities that manage natural resources have taken on this kind of approach. One interviewee noted that the Nature Conservancy Conservation Action Planning process (TNC, 2011) has provided a precedent that helps shift from micro-level management (e.g., species) to macro-level management (e.g., habitat). In Wyoming, “area based management” is the new norm for sage grouse in order to provide sufficient habitat for this species to survive despite habitat fragmentation and other stressors. This approach could help improve resilience to climate change. And many conservation organizations have begun to grapple with the idea of shifting species and baselines and are adapting their conservation planning to accept and even facilitate ecosystem change.

Although this new approach is being taken seriously by many entities, some challenges remain. For example, if a protected area was designed to protect a key species of concern, but that species’ range moves out of the protected area, should the area still be conserved? If a species needs to move to a more northerly habitat fragment to survive locally, but there are no possible corridors for movement, should managers facilitate their migration?

In addition, it is not only land and resource managers who need to grapple with and accept the likelihood of changing baselines and species shifts, but also critical stakeholders who are often engaged with natural resource conservation and use. The public and policymakers will likely need to be educated about new norms to expect and how management plans can and cannot work against these new norms. For example, the public is often galvanized by efforts to save particular species, but if that species disappears, efforts might need to instead focus on the conservation of different habitat types. This might pose a communications challenge for managers.

6.3 Policy Recommendations

Based on our archival review and interviews, we present our synthesis of a few policy recommendations for OSMP and BCPOS. These recommendations are intended as immediate actions items that can help prepare both agencies for climate change.

6.3.1 Convene a multi-agency work group to coordinate resource management strategies across jurisdictional boundaries

A broad consensus existed across all interviewees that greater coordination across land management agencies would be useful on a number of issues, including fire management, noxious weed management, recreation management, and more. Just within Boulder County, BCPOS, OSMP, the U.S. Forest Service, the National Park Service, the Bureau of Land Management, and Colorado State Parks hold significant land area. Yet coordination of management strategies across these jurisdictions is relatively rare. A few precedents do exist. For example, in the Front Range Fuels Treatment Partnership, federal, state, and local governments, land-management agencies, private landowners, conservation organizations, and other stakeholders are working in collaboration to reduce wildland fire risks and restore healthy forest ecosystems along Colorado's Front Range. Such a partnership could economize on resources, leverage monitoring networks, and more. There are also historic precedents for this, including the "resource managers' roundtable" which operated in the late 1980s and early 1990s as a collaborative among personnel from the City Open Space Department, the City Mountain Parks Department, Colorado State Parks, the Division of Wildlife, and others. The Colorado Open Space Association conference is a more modern example, but not specific to Boulder County.

6.3.2 Promote and foster biodiversity and ecological resilience to reduce species vulnerability

Several interviewees suggested that the best hedge against climate change is to remove other stressors from the ecological context of sensitive species. For example, reducing competition with invasive species, reducing mortality from roadways, and providing refuges for successful breeding and reproduction can all increase reproductive success and survival in a way that allows a particular species to better absorb other stresses, such as climate change. These actions can be taken now to reduce stress on specific species of concern to enable them to better absorb the anticipated stress of climate change. Although this recommendation holds some merit, it is important to consider it in light of the evolving focus on stress to ecological systems and not just single species.

6.3.3 Expand and enhance monitoring networks for climate data

Significant monitoring efforts are already underway by OSMP and BCPOS. These monitoring networks should collect relevant climate data along with observations relevant to the management objective. This will allow for large, relevant datasets to be generated that could be used in the future to establish climate correlations with species and habitat shifts. We need to determine how to capture meaningful changes in climate while maintaining the high-quality observed datasets that now exist. Furthermore, wildlife monitoring is typically species or community specific, but many such monitoring projects have quality baseline data at this point. According to interviewees, there is no ecosystem-level monitoring in place due to resource constraints. However, there might be ways to combine observations from multiple monitoring projects to develop a habitat-level picture.

6.3.4 Reassess acquisition priorities

It is not clear from the archival review and interviews how acquisition priorities are set for OSMP and BCPOS. But we recommend a high-level review of acquisition priorities in light of the anticipated impacts of climate change. Existing priorities for acquisition might adequately address the greatest anticipated impacts, such as impacts on ecosystems and water resources. But there might be specific species or resources of concern, where more habitat connections to high-elevation public land might be necessary to facilitate species migration in the face of climate change. This recommendation could also play out in the form of partnership agreements between public land agencies in lieu of acquisition. This could provide a more cost-effective way to accomplish a similar end and ensure compatible management across jurisdictional boundaries.

6.3.5 Ask the climate question in system-wide management plans

One way to ensure that climate change is adequately considered in management plans is to simply “ask the climate question.” Climate change should be one of the many considerations in a management plan, but without detracting from the important work of plan development. Actively looking for and explicitly calling out resource vulnerabilities to climate variability and change in planning documents and recommending adaptive management to cope with unrealized potential impacts can be a constructive addition to current management planning. As one interviewee stated, “we shouldn’t simply say that [climate change] is out there, but we don’t know what to do about it.”

6.3.6 Prioritize information transfer on climate change issues

Many organization involved in agriculture and natural resource management are engaged on the climate change issue, such as The Nature Conservancy, the Natural Resources Conservation Service, the National Park Service, and others. Learning from the successful innovations of these organizations is a low-cost way to stay abreast of the state of the practice, not just on climate change, but on many resource management issues. Because resource management is a relatively diffuse activity, without tight-knit professional organizations, trade journals, conferences, or continuing education requirements, this recommendation could help fill a hole in organizational learning for OSMP and BCPOS.

6.4 Recommendations for Future Study

Many ideas and suggestions were developed during the course of our research. Interviewees and expert reviewers suggested many more. Ideas and recommendations judged premature for immediate policy action are included in this section as possibilities for further study or research.

6.4.1 More research on the regional impacts of climate change on natural resources

In addition to the specific concern about thresholds, another desire brought up by many interviewees was for more region-specific research on the potential effects of climate change on natural resources (region-specific species, communities, and ecosystems). Many interviewees recognized that such research might not be capable of fully answering the many outstanding questions about climate change impacts, but interviewees suggested soliciting research at the local level tailored to management needs. A study that examined climate change and prairie dogs was mentioned as a good example by one interviewee.

A specific issue that was brought up by many interviewees was the issue of ecosystem thresholds. This is the idea that although climate change might be gradual, ecosystems can respond in non-linear, dramatic ways after a given threshold is reached. (An example of this kind of dynamic is the mountain pine beetle, whose populations exploded in western North America because of recent winter warming.) Although the potential for thresholds is widely recognized, very little is known about which species or ecosystems are at risk and how to detect thresholds before they are crossed.

6.4.2 Investigate challenges to using controlled burns under a climate altered future

A healthy fire ecology is critical to current management of grasslands and forests. Active management of fire is currently necessary to maintain or improve ecological conditions due to a long history of fire repression in Boulder County and throughout the intermountain west. But the ability to control burns might be compromised if temperatures get too high, precipitation decreases, and vegetation drying presents high-hazard situations. Considering these possible climate changes as we begin to conduct more frequent and organized controlled burns will allow us to better anticipate the associated challenges and to adapt to these more difficult conditions over time.

6.4.3 Consider the role of climate in integrated pest management

In Boulder County, significant public pressure exists to minimize the use of pesticides and genetically modified organisms for integrated pest management (IPM) for both agriculture and natural habitats. Unfortunately, pesticides often prove far more effective than alternative means such as mechanical thinning and biological control. And biological control will typically be more sensitive to climate conditions than conventional pesticide use. Under such challenging circumstances, it might make sense to further study the likely effects of climate change on IPM. IPM, in the form of weed control, is further determined by the Colorado Department of Agriculture's determination of List A, B, and C invasive species. It is possible that climate change might change the relative threat ranks of different weeds, and this should be further examined.

6.4.4 Examine increasing the flexibility of agriculture practices

Currently, informal practices help maintain the necessary flexibility to ensure that natural resources are not adversely affected by extreme climate conditions. It will be important to maintain such flexibility, either through the existing informal practices or through more formal management in the future. But the flexibility of lessees to alter grazing or farming practices temporarily during critical periods of stress for sensitive species might be challenged if those conditions are reached more often. This can also play out just within the agriculture sector. During periods of insufficient water, state law currently gives the water to the "first in right." But a broader approach to agriculture that considers which lands will be most productive with a given water allocation might yield greater agricultural output than the current system. In the worst-case scenario, marginal lands with senior water rights could force more productive agricultural lands to lie fallow while they fail to generate significant produce due to insufficient water. Water lease agreements between cities and agricultural users might provide a useful precedent for optimizing irrigation water among agricultural users.

6.4.5 Consider increasing flexibility in mandates and regulations

Some resource management practices are required by state or federal regulations. Ensuring compliance with these regulations might present some barriers to adaptation. An example at the state level is noxious weed eradication. Noxious weeds species are classified as A, B, or C based on the threat posed by the species. Eradication is required for list A species. The number of species on this list could increase under changing climate conditions. Some flexibility to set priorities for action among A-list species might be needed. A related issue is how to come to grips with the fact that the world is changing and some species designated as invasive now might in fact become the best suited to inhabit a given area under a climate-altered future. Climate change could also cause weed eradication costs to increase significantly. This might divert resources from other departmental objectives. Partnering with regulators to allow for flexible compliance will promote optimal adaptation integration.

6.4.6 Investigate potential competition for land under climate change

If climate change or other global trends adversely affect food production, this could generate increased demand to put into production land previously devoted to wildlife and habitat conservation. It is important to be forward thinking about the trade-offs and synergies between the multiple objectives of open space to ensure that climate change does not favor one to the exclusion of the other.

6.4.7 Consider the potential efficacy of public outreach regarding climate change

The communications specialists for both OSMP and BCPOS suggested that there could be an important role for public outreach in communicating about climate change and the impacts it might have locally on natural resources. This issue might merit further consideration. For example, observed impacts of climate change might present opportunities to educate the public about climate change and its consequences. Even though attributing climate change at a local scale is scientifically challenging, education can identify the types of changes that we expect to happen.

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7. A Climate Change Resilience Strategy for Boulder County and the City of Boulder

As described in Chapter 1, the goal of crafting this plan is to assist county and city agencies that manage climate-sensitive resources and assets in achieving their departmental objectives in the face of challenges posed by projected climate changes. Chapter 2 demonstrates that temperatures already have begun to rise in Colorado, that the best available climate science projects further warming, and that higher temperatures are likely to lead to significant impacts on a variety of resources managed by Boulder County, the City of Boulder, and other local municipalities. To manage these projected impacts, this plan assessed challenges, capabilities, and opportunities for Boulder County and its municipalities to adapt to climate change in four key sectors: water supply, EM, public health, and agriculture and natural resources.

In addition to the sector-specific recommendations discussed in Chapters 3–6, this plan proposes an overarching climate resilience strategy. There are many aspects of county and city government that are too broad to be captured in a single sector. These include community planning through the Boulder Valley and Boulder County Comprehensive Plans. Furthermore, the jurisdiction of many county and city agencies is limited and cannot effectively address cross-sector adaptation challenges or opportunities. Consequently, this chapter provides direction for a broad-based climate resilience strategy that can be adopted and implemented by Boulder County and City of Boulder elected officials, as well as those from other municipalities. Below we overview that strategy along with principles of best practice to help guide decision-making to manage the effects of climate change in Boulder County.

7.1 County- and City-Wide Climate Resilience Strategies

The key to the development of an effective climate resilience strategy is to understand how climate change could affect specific objectives of the city or the county. Although Chapters 3–6 provided examples relevant to specific sectors, this same approach can be applied both at the broader level of county or city government as a whole as well as to other sectors not covered in this plan. For example, Boulder County's sustainability objectives cover a variety of goals such as the conservation of resources, a high quality of life, the protection of ecosystems, and the promotion of an active community. Ensuring that climate change will not significantly impede efforts to balance and meet these goals will require the application of an overall resilience strategy – but not necessarily a formal policy or plan – applied at the county level.

It is important to recognize that the strategy described here does not require a vastly different manner of thinking or the development of significant changes in policy. In other contexts, bolstering resilience and developing adaptation efforts have been found to work best when climate change considerations are addressed in an integrated fashion along with other considerations such as changes in population, land use, and citizen preferences. At its core, resilience is essentially about preparing for change – change in climate but also changes in other factors that have important influences on resource and HM.

Consequently, Boulder County and its various municipal governments should continue to focus on their core objectives as articulated in their comprehensive plans and HM plans. The challenge of climate change is not to engage in an entirely new planning effort on top of the already significant municipal planning efforts underway. Rather, the challenge is to integrate climate change among other concerns into ongoing planning efforts by city and county governments. Simply put, climate change is an additional factor that might affect county and municipal planning, policy, and operations. This is particularly relevant in considering decisions with long-term consequences or major investment requirements, like water supply planning or significant infrastructure investments.

7.2 Principles of Climate Resilience

This section provides strategic-level advice for managing the impacts of climate change in Boulder County. The purpose of these principles is not to suggest specific actions or policies but to provide a perspective generated from the state of the practice in climate change adaptation.

Ask the climate question. All of the agencies examined for this report are largely accomplishing their organizational objectives at present. Some agencies, however, do not consider climate at all in their decisions, while others consider current climate variability only but do not consider change in that variability over time. To ensure that the impacts of climate change are taken into account, these agencies need to incorporate the practice of asking "the climate question" in all management, planning, and policy activities. Asking the climate question essentially entails considering if and how current weather and climate or projected future changes would affect the objectives of an agency or the resource it manages.

Promote adaptive management. Many of the actions of individual departments and agencies reviewed for this report indicate a strong commitment to adaptive management. Rather than making a decision or crafting a plan and following it reflexively, adaptive management entails reviewing policies and plans during implementation to take into account changes in many factors that could affect the ability of the prescribed actions to accomplish the stipulated objectives. With respect to climate change, an agency should strive to monitor climate conditions and impacts on climate-sensitive resources and be prepared to consider changes in management between specified plan or policy updates, if warranted.

Ensure flexibility. As a result of uncertainties regarding the magnitude and the timing of climate changes, and because the climate is likely to continue changing for many decades, flexibility is critical in the design and implementation of policies and in planning. Departments that deal with climate-sensitive resources already pursue flexible policies to account for drought years as well as wet years and extremes in both heat and cold. The assumption is that conditions will eventually return to normal. Climate change adds the possibility of so-called normal conditions changing. It is therefore critical that flexibility be built into year-to-year and multi-year timeframes to enable policies to evolve as the climate and other conditions change.

“Mainstream” adaptation. Rather than create an entirely new or parallel set of programs and policies to cope with climate change, it would be better to incorporate consideration of climate change into existing decision-making, a concept known as “mainstreaming.” Many of the natural resources and human systems that will be affected by climate change in Boulder County are already heavily managed systems. Where established agencies already are making climate-sensitive decisions or could be retasked to do so, they are the best starting point for mainstreaming climate change. Working with existing institutions to integrate climate considerations leverages existing resources, requires minimal resources to implement, avoids the disruption that reorganization can create, and generates less opposition than does creating new institutions.

Learn from best practices. Many departments within city and county governments are already managing the effects of existing climate variability, while others have begun to actively prepare for climate change. Departments that have not already begun to consider preparing for climate change impacts to the resources they manage or their objectives should start by examining how their own staff already employ a variety of methods to adapt to climate variability. For example, emergency managers are prepared every year to deal with a wide variety of natural hazards as well as the occasional extreme event; the same principles used there could be used in dealing with long-term trends. In addition, departments can review actions taken by other city and county agencies and look for lessons learned and policy innovations that can be applied to other departments. The City of Boulder’s water utility has engaged in extensive scientific analyses of the impacts of climate change on water resources. It makes sense for other agencies to learn from the experience of this department before committing to a particular course of action.

Remove barriers to adaptation. Many existing laws, programs, policies, and management approaches were put in place assuming that the climate does not change over the long term. As a result, some of these approaches can function as barriers that discourage or prohibit adaptation to a changing climate or promote behavior that increases vulnerability to climate change. For example, the Colorado State Division of Wildlife’s designations of noxious weeds could constrain city and county government weed management decisions as climate changes. It is critical that agencies are able to recognize the barriers inherent in possibly outdated management approaches that constrain the variety of options available to best manage the impacts of climate change. As noted in Chapter 6, open space managers at OSMP and BCPOS have recognized the barrier of managing for species-level objectives and have begun to consider using habitat-level objectives instead.

Recognize the scales at which decisions are made. Adaptation decisions will have to be made at multiple geographic and decision-making scales involving federal and state agencies, Boulder County, and individual municipalities, as well as the private sector, NGOs, and individuals. Although Boulder County, the City of Boulder, and other municipalities should first and foremost support their own adaptation activities, such as those described in Chapters 3–6, they should also enable each other as well as the private sector, NGOs, and individuals to plan for climate change and take adaptive actions.

Recognize the need for leadership and collaboration. A county- or city-wide program to manage climate impacts must be highly visible and promoted as a community priority. This sends a strong signal to individual departments and agencies that adaptation is a community priority and it incentivizes collaboration, provides responsible staff with authority, and supplies the focus and resources necessary to make a climate resilience program successful. County Commissioners and City Council members can provide this leadership by ensuring that department directors are following the principles laid out in this plan.

Establish clear lines of authority. It must be clear who is in charge of working toward climate resilience across an entire jurisdiction and within specific departments. Such transparency promotes responsibility and accountability and ensures that someone is responsible for asking "the climate question."

Create mechanisms to address impacts that cross jurisdictions. Many climate impacts will cross geographic or organizational jurisdictions such as property lines and different levels of government. A climate resilience strategy should include mechanisms to coordinate across these boundaries and with the private sector, NGOs, and other stakeholders. The Climate Adaptation Planning Committee (CAPC), established to guide the development of this plan, is a potentially effective mechanism for accomplishing this goal. A group like the CAPC should be formally recognized and meet regularly to oversee the implementation of this plan's recommendations.

Involve stakeholders. Those affected not only by climate change but also by departmental decisions made in light of climate change should be involved in developing policies to manage impacts. This will help ensure that policies meet the needs of those affected by climate change and that those affected will "buy in" to proposed policies. Stakeholder involvement can also help ensure policy design and implementation sensitive to the local context.

Engage in "no-regrets" decision-making. "No-regrets" decisions pay dividends regardless of what happens in the future. Making decisions that allow a department to reap benefits under a number of possible future climate scenarios is a perfect example of "no-regrets" adaptation. For example, the City of Boulder has amended its code to give the city first right of purchase when ditch rights within city limits are up for sale. This decision could allow the city to obtain more water if needed due to future climate impacts, but even without climate change, it provides the city with greater control over its own supplies.

Prepare for multiple possible climate futures. Although this report provides the best available science related to climate change impacts in Boulder County, there is still a great deal of uncertainty surrounding changes to certain climate parameters and secondary effects. In addition, climate science is an area of active research, and projections are being constantly refined as scientists learn more about the climate system. This can result in changes to expected or projected impacts. Thus, rather than looking for climate projections to provide specific guidance on the exact nature of future changes, managers and planners should review the information provided in this plan but also prepare for the possibility that there could be a range of future climate conditions. A future with less overall precipitation, more fires, and high population growth might require a different approach than a future with more overall precipitation and more flooding. Resilience will entail the county and its municipalities being prepared to anticipate and react to multiple scenarios.

Use available scientific resources. Boulder is home to a number of world-class university, federal, and other scientists who can provide a wealth of knowledge and guidance regarding climate change and its impacts. The county and city should assign staff the responsibility of building connections with scientists and other resources to provide updates and interpretation of the latest science. At the same time, county and city officials should recognize that climate science is an active area of research and should avoid assuming that research results are specific forecasts of future changes or impacts.

7.3 Policy Recommendations

Based on our archival review and interviews in all four sectors examined for this plan, we present our synthesis policy recommendations. This includes the specific policy recommendations for each sector as well as some additional recommendations that are cross-cutting or beyond the scope of a single agency. These recommendations are intended as immediate actions items that can help prepare Boulder County, the City of Boulder, and other municipalities for climate change.

7.3.1 Cross-cutting policy recommendations and plan implementation

During the development of this plan, numerous county and municipal staff expressed concern that it could merely sit on a shelf and be ignored, rather than being a guiding document to be used during planning and policymaking efforts. The following recommendations on plan implementation and maintenance are intended to help avoid such an outcome.

Incorporate adaptation principles into comprehensive planning. The County Comprehensive Plan is intended to provide overall guidance on land use and growth throughout the county. As of September 2011, it is currently undergoing its first significant update in 15 years. The current set of plan goals covers a wide variety of issues, but none of those goals explicitly mention preparing for possible climate change impacts. Adding in overarching language instructing the county to consider the need to prepare for the consequences of climate change could help set the stage for further action in both land use planning and other aspects of county government. Similar considerations could be brought to bear on future revisions of the Boulder Valley Comprehensive Plan.

Assign a point person to coordinate adaptation activities. To ensure progress and to provide for coordination across government agencies, Boulder County and the City of Boulder should strongly consider assigning individuals with the task of coordinating climate resilience efforts, tracking progress, and leveraging county- or city-wide resources. Both Boulder County's and the City of Boulder's Sustainability Coordinators are likely candidates to help facilitate adaptation practices in the planning and policymaking of all relevant departments. The coordinators would also have the responsibility of tracking progress and ensuring that climate resilience remains a priority at various departments. Additional staff or resources might be necessary to manage this increase in scope for these positions.

Establish a permanent CAPC. The initial CAPC was set up to provide advice on the development of this plan. We recommend formally establishing it as an inter-departmental and inter-governmental committee that helps coordinate relevant activities across Boulder County. This group would be charged with tracking progress toward resilience objectives, facilitating cross-departmental and multi-jurisdictional conversations relevant to climate and climate change, and ensuring that planning, policy, and operations have effectively considered potential climate impacts.

Revisit the climate resilience plan. At least once a year, this plan should be assessed in terms of its relevance to actual county and city planning and policymaking, its success in spreading adaptation thinking to other departments, and whether the scientific information in it is up to date. The plan should be formally updated every five years, although progress toward specific objectives should be assessed regularly.

Continue and expand public involvement. Continued public involvement could enhance the overall success of the plan. The update process provides an opportunity to publicize success stories from the plan implementation and seek additional public comment. Public hearing(s) to receive comment on potential changes and improvements to the plan could be held during the update period. When the CAPC reconvenes for the update, they could coordinate with stakeholders to update and revise the plan. The plan maintenance and update process could include continued public and stakeholder involvement and input through attendance at designated committee meetings, web postings, and press releases to local media.

Expand sectors included in plan update. This initial climate resilience plan focused on only four sectors. For future plan updates, it may make sense to include other sectors of interest, such as transportation, that were not included in this effort. Engaging the public, staff, elected officials, and others can help ensure that important issues that were not covered here receive appropriate attention in future plan updates.

Expand communities included in plan update. This initial climate resilience plan focused on Boulder County and City of Boulder government agencies and management responsibilities. There are a number of other municipalities in Boulder County that could benefit from being included in future plan updates or engaging in more specific vulnerability assessment efforts. While many of the larger municipalities may be able to gather much of the needed information from what is included here, there are a number of unique communities throughout the county that may face significantly different types of issues – such as small mountain towns or unincorporated agricultural areas.

Expand community-wide education and outreach. Educate the public and elected officials about the uncertainties inherent in climate change and climate change projections and set the stage for potential discussions about how to consider updating county and city policies to improve adaptation.

7.3.2 Sector-specific policy recommendations

The following recommendations come directly from each of the sector chapters. For a more detailed description of each of these recommendations, please refer to the identified chapter.

Water supply (see Chapter 3)

- Create a climate adaptation learning network for water
- Provide a means to translate and communicate climate science
- Plan for a variety of different climates

- Ensure funding and support for "no-regrets" projects
- Provide a forum for community dialogue on water and climate
- Coordinate with EM officials
- Develop source water protection policies
- Prepare for the consequences of severe wildfires on water resources
- Continue public outreach on reliability criteria
- Prioritize BCPOS investments in water efficiency improvements.

Emergency management (see Chapter 4)

- Continue to reduce vulnerability to hazards through implementation of mitigation recommendations within Multi-Hazard Mitigation Plans and master plans
- Incorporate climate change considerations in next update to the Multi-Hazard Mitigation Plans for the County and City of Boulder
- Incorporate "recovery mitigation" considerations in next update to the Multi-Hazard Mitigation Plans
- Continue recovery planning effort underway
- Continue to enhance flood detection network
- Continue Boulder's EM efforts for process improvement and self-assessment
- Hire a full-time CWPP coordinator
- Adopt and implement the City of Boulder critical facilities and mobile populations ordinance
- Continue to enhance city and county floodplain management programs through participation in the NFIP's CRS
- Evaluate the possibility of including higher regulatory standards for critical facilities protection in the county's floodplain management ordinance
- Continue to prepare studies that will facilitate rapid recovery from floods and wildfires.

Public health (see Chapter 5)

- Develop a comprehensive county recovery plan
- Advocate for consideration of public health impacts in other climate change – related decision-making arenas
- Enhance community public health partnerships
- Encourage viewing climate change in terms of specific challenges and impacts.

Agriculture and natural resources (see Chapter 6)

- Convene a multi-agency work group to coordinate resource management strategies across jurisdictional boundaries
- Promote and foster biodiversity and ecological resilience to reduce species vulnerability
- Expand and enhance monitoring networks for climate data
- Re-assess acquisition priorities
- Ask the climate question in system-wide management plans
- Prioritize information transfer on climate change issues.

7.4 Recommendations for Future Study

Based on our archival review and interviews in all four sectors examined for this report, we present our synthesis recommendations for future study. Many ideas and suggestions developed during the course of our research were judged premature for immediate policy action, but are included in this section as possibilities for further study or research. This includes the specific research recommendations for climate science, for each sector, as well as some additional recommendations that are cross-cutting or beyond the scope of a single agency or sector.

7.4.1 Cross-cutting and government-wide recommendations

Beyond the specific recommendations for further research outlined in each sector chapter and the science chapter, a number of cross-cutting or government-wide recommendations for future study were identified that were either relevant to more than one sector or could not be implemented within the confines of a single sector.

Specific implications of climate change scenarios on frequency and magnitude of fire and floods. In addition to having perhaps the most significant impact on lives and property, natural disasters affect the operations of most departments in the County and City of Boulder. More specific research on how fires and floods, perhaps the most climate-sensitive and destructive natural hazards in our area, might change in the future could guide EM and a variety of planning efforts.

Sociological research on residents' perception of climate hazards, level of concern, and level of awareness. In addition to technical studies based on physical science, the county and city could greatly benefit from an understanding of how citizens perceive risks from future climate change and their tolerance for taking steps to address those risks. A study of baseline attitudes could also help the city and county better understand the effectiveness of its efforts to get residents involved in adaptation.

Economic implications for the county and city of various disasters, potentially using the HAZUS model developed by FEMA. Existing modeling software makes it relatively easy to understand costs of various disasters. Using such software to focus on Boulder County impacts could help prepare resources for disaster planning and recovery.

Evaluation of best practices from climate resilience and adaptation plans in other jurisdictions. A number of similar-sized cities and counties have implemented or begun to implement adaptation planning efforts. Have those been successful? What best practices can Boulder learn from other jurisdictions? The county's existing participation in an effort among Intermountain West cities can help and should be encouraged, but much more information is available.

Develop a set of metrics to measure progress and potential success in Boulder's climate resilience efforts. As with any new effort, it is important to set standards for understanding whether or not climate resilience planning efforts in Boulder are succeeding. Because resilience planning requires preparing for impacts that have not yet happened and can be difficult to measure without long-term indicators, the city and county should work with adaptation experts to understand how to define success and monitor for both climate change impacts and the effectiveness of city and county preparations and responses.

Implications of climate change on natural vegetation. Natural resources management and EM will benefit from an understanding of the implications of climate change on natural vegetation. Much of this understanding likely can be gained from the published results of ongoing and future research, but some studies specific to Boulder County might be beneficial.

7.4.2 Sector-specific future research recommendations

The following recommendations come directly from each of the sector chapters. For a more detailed description of each of these recommendations, please refer to the identified chapter.

Science (see Chapter 2)

- Periodic review of the state of the science
- Develop and strengthen connections with the climate science, impacts, and adaptation research community in Boulder
- Explore partnering with researchers where gaps in knowledge can be addressed with further research
- Conduct a comprehensive climate information needs assessment across departments and other entities in Boulder County
- Consider developing guidelines on how climate impacts studies are to be implemented in order to provide some measure of consistency across departments
- Develop projected climate data and derived products in formats that are useful to the various departments, to serve the preparedness needs identified in this report.

Water supply (see Chapter 3)

- Additional research on water quality impacts from climate change
- Leverage Joint Front Range Climate Change Vulnerability Study and other resources to develop more specific vulnerability analyses for specific water supply entities
- Examine case studies of other water supply entities around the country that have developed approaches to planning for uncertain futures.

Emergency management (see Chapter 4)

- Further research and modeling on economic impacts from disasters
- Continued research, monitoring, and information on climate change impacts
- Continue to update floodplain maps and flood studies
- Evaluate the impacts of climate change on transportation infrastructure.

Public health (see Chapter 5)

- Extreme heat impacts and extreme heat program needs assessment
- Qualitative ranking of potential new health stressors attributable to climate change
- Evaluate results of research from NIH mental health grants and/or other areas of climate change impacts to mental health study.

Agriculture and Natural Resources (see Chapter 6)

- More research on the regional impacts of climate change on natural resources
- Investigate challenges to using controlled burns under a climate-altered future
- Consider the role of climate in IPM
- Examine increasing the flexibility of agriculture practices
- Consider increasing flexibility in mandates and regulations
- Investigate potential competition for land under climate change
- Consider the potential efficacy of public outreach regarding climate change.

7.5 Conclusions

As simple as it sounds, a core element of climate change resilience planning is getting started. The climate is already changing and impacts are becoming increasingly evident. However, some uncertainties about future climate will always persist. Many organizations consider climate adaptation efforts but come to a standstill in light of this fact, concerned that uncertainty makes it too difficult to take action. However, deciding not to act is in and of itself a decision to accept the potential risks associated with the status quo. In many cases, substantial progress can be made on reducing the vulnerability of human and natural systems by engaging in common sense and cost-effective policy and research such as the recommendations included in this plan. Through this effort to prepare for the impacts of climate change, Boulder County and the City of Boulder have shown leadership on adapting to a changing climate just as they have already showed leadership on mitigating GHG emissions.

City and county managers dealing with natural resources and human systems sensitive to climate change need to begin implementing the recommendations contained in this plan to begin the process of understanding and managing the risks and opportunities posed by climate change. Recall that the purpose of this report is to "assist county and city departments that manage climate-sensitive resources and assets to achieve their departmental objectives in the face of challenges posed by anticipated future changes in the climate of Boulder County." This plan is intended to identify the potential impacts of climate change, to explore the implications of these changes in the context of resource management institutions, and to outline opportunities for adaptation planning efforts. It should serve as a resource for county and municipal planners as they integrate climate change, in addition to other concerns, into their ongoing planning efforts.

Once adopted, however, this plan faces its most critical test – implementation. While this plan contains useful information and many worthwhile policy and research recommendations, each agency or department with authority over one of the sectors included in this plan will need to decide which action(s) to undertake first. We recommend using the Principles of Climate Resilience in Section 7.2 to guide implementation. Asking the climate question, mainstreaming adaptation, and no regrets decision-making may be the easiest and lowest risk ways to begin plan implementation. Assigning a point person to coordinate adaptation efforts, track progress, and leverage county- or city-wide resources may also facilitate implementation by establishing clear lines of authority, facilitating the diffusion of best practices, and facilitating collaboration.

As a final note, the reader should recognize that this plan is a starting point for further work. It is not intended to be the end of climate resilience planning in Boulder County and the City of Boulder, but rather an outline for making progress. Instead of dictating a comprehensive climate change adaptation policy, this document is intended to expand the focus of attention of resource managers, management administrators, and elected and appointed officials within and across departments and between and across levels of government. In the end, it is most effectively used as a resource to bring climate considerations to bear on the everyday management, planning, and operational decisions of city and county decision-makers.