Climate Change & Aspen

An Update on Impacts to Guide Resiliency Planning & Stakeholder Engagement

A report of the Aspen Global Change Institute

Prepared for the City of Aspen

ASPEN GLOBAL CHANGE INSTITUTE

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Prepared December 2014

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About AGCI

AGCI is an independent Colorado non-profit founded in 1989. The mission of the Aspen Global Change Institute (AGCI) is to further the scientific understanding of Earth systems and global environmental change through collaborative research projects, interdisciplinary scientific workshops, consulting, educational programs, publications, and videos. This work of regional to global significance provides new scientific understanding of critical environmental issues such as climate change, land-use change, and biodiversity loss, while improving scientific literacy and informing decision making and policy formation. AGCI collaborates with the science research community, governmental entities, stakeholders, students, and the public to accomplish its mission.

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FOREWARD

Climate change, a global issue with local consequences, poses a threat to Aspen's future. Increasing temperatures reduce our snowpack, changing water cycles diminish our rivers, and elevated risks of wildfire and landslides threaten our wilderness, property and health and safety.

Aspen's City Council, both current and former, have prepared for climate change. Though we've enacted a number of aggressive policies, two are vital: reducing our greenhouse gas emissions - a primary driver of climate change; and establishing a resiliency plan to help us address vulnerabilities in our local economy and environment. Both are aggressive, but necessary.

The following report prepared by the Aspen Global Change Institute, *Climate Change & Aspen: An Update on Impacts to Guide Resiliency Planning and Stakeholder Engagement*, is intended to help inform the resiliency planning effort. It updates the 2006 report and speaks to planning needs around critical areas that climate change affects, including: recreation and tourism, ecosystems, public health and safety, built environment and infrastructure, energy, and importantly, water.

I hope you'll find this report valuable, learn lessons from it and use the information to plan for a stronger, more resilient Aspen.

Thank you,

Steve Skadron, Mayor
December 22, 2014
Aspen, Colorado

PREFACE

Since the City of Aspen formally adopted a Climate Action Plan in May 2007, public awareness and concern about climate change has increased, yet societal actions remain nominal relative to the enormity of the challenge. This elevates the risk of near and long-term climate impacts to people and ecosystems—both in Aspen and worldwide.

Although aggressive action—globally and locally—is needed to address the root causes of climate change, local communities such as Aspen are complementing their efforts to reduce greenhouse gas emissions by also planning for the impacts arising from climate change, some portion of which are now unavoidable.

President Obama acknowledged the need to prepare for the impacts of climate change in June 2013 when he pledged his administration would "partner with communities seeking help to prepare for droughts and flood, reduce the risk of wildfires," and "make sure that cities and states assess risk under different climate scenarios so that we don't waste money."[1] It is clear from recent history and future projections that Aspen will face many of the impacts mentioned by the President, as well as additional changes, such as heat waves, altered precipitation, and dust on snow affecting mountain snowpack and the timing of runoff, all of which could alter the economic, cultural, and ecological lifeblood of the Aspen community.

Communities like Aspen can lead the way in planning for the impacts arising from climate change, some portion of which now appear unavoidable.

The City of Aspen has been a leader among cities—both large and small—in acknowledging the risks associated with climate change and pursuing aggressive and measurable actions that reduce greenhouse gas emissions. While still eager to continue visionary greenhouse gas mitigation programs, the City is now also working to prepare for climate change.

The following report serves as an update to an initial 2006 report by AGCI entitled, *Climate Change and Aspen: An Assessment of Impacts and Potential Responses*.[2] We hope the following report will be a useful complement to the earlier study and that it will make an important contribution to the City's work towards resiliency planning. Like the 2006 report, we are not intending to recommend specific actions or policies to pursue but rather offer ideas, observations, projections, and stakeholder perspectives that may be useful as a starting point in engaging the community on preparedness.

[1] Obama, Barack. 2013. "Remarks by the President on Climate Change" (speech, Washington, DC, June 25, 2013), White House. http://www.whitehouse.gov/the-press-office/2013/06/25/remarks-president-climate-change

[2] Aspen Global Change Institute. 2006. Climate Change and Aspen: An assessment of impacts and potential responses. Available at: http://www.agci.org/dB/PDFs/Publications/2006_CCA.pdf

EXECUTIVE SUMMARY

Aspen's climate is already changing, and additional changes are anticipated throughout the 21st century and beyond. These local climate shifts will take place within the context of regional and global changes, all of which may result in conditions unprecedented in human history. The impacts of climate change are likely to affect Aspen's residents, ecosystems, and environmental amenities as well as the home communities of Aspen visitors.

For Aspen, climate change will likely include longer summertime warm periods, earlier onset of spring snowmelt, more precipitation arriving as rain rather than snow, and longer dry periods with heavier precipitation events in between. These types of changes could exacerbate already risky wildfire conditions, place extra pressure on already stretched water providers and users, provide additional challenges to ski area operators and other winter and summer recreation providers, as well as result in other impacts to every sector important to the Aspen community. Alongside the many challenges, new opportunities may also emerge, such as the possibility for expanded summertime activities.

The following report considers observations, climate modeling projections, relevant research from the literature, and stakeholder perspectives to explore climate change in Aspen as a basis for resiliency planning. Based on this effort, seven key findings emerge.

Seven key points

1. **Climate change continues to be an issue of global concern** with mounting evidence of current and future impacts to society and ecosystems. A consensus among decision-makers, citizens, and scientists is steadily growing and calls for action on emissions reduction and preparedness at international, regional, and local levels.

2. **Temperatures in Aspen during all seasons have increased since 1940,** and the summertime frost free period has lengthened by over one month. Precipitation and snowfall have declined slightly since 1980, although an overall increase has been observed since 1940.[3]

3. **Climate model results for the Aspen region project rising temperatures and alterations to precipitation over the 21st century,** and a key determinant of the magnitude of these changes will be future global greenhouse gas emission levels.

4. **Impacts from observational trends and future projections will affect critical sectors of the Aspen community,** including water, energy, recreation and tourism, public health and safety, ecosystems, and the built environment.

5. **Local stakeholders are concerned about climate change and its impacts on their environment, business, and/or personal well-being**. Many of the stakeholders interviewed for this report indicate they are already taking climate change into account for current decision-making and will likely continue to do so during future planning.

6. **Resiliency planning and implementation can help reduce vulnerability to anticipated impacts as well as exploit beneficial opportunities.** This effort is strengthened through stakeholder engagement and involvement, ongoing monitoring and evaluation, and processes that allow for flexible response strategies as both anticipated and unanticipated changes emerge.

7. **Significant reductions in greenhouse gases are a necessary part of ensuring resiliency.** Efforts to plan for the impacts of climate change will be more difficult, more expensive, and less likely to succeed if near-term strategies for emissions reductions are not enacted.

While ongoing efforts to reduce the root causes of climate change are still urgently needed, preparedness planning for future scenarios of climate-related impacts are also an essential component of society’s response to climate change. By pursuing resiliency planning as a strategy for preparedness, the City of Aspen continues its legacy of leadership on climate change issues.

The aim of this report is to serve as an update to a previous study conducted by the Aspen Global Change Institute in 2006. The findings presented here offer an assessment of observations, modeling, climate impacts research, and interviews intended to provide a

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[3] In 1980, the Aspen weather station underwent a change in location, moving approximately 200 feet higher in elevation.

groundwork of scientific and stakeholder input to inform and support the City's resiliency planning process. While scientific understanding has expanded and improved since the time of the 2006 study, the results of this work largely reconfirm its main conclusions.

Climate change is a global challenge requiring local and global responses

Globally, surface air temperatures have increased 1.5ºF (0.8ºC) since 1880. Projected future increases range from slight to staggering and are primarily dependent upon future emissions. As Figure 1 illustrates, average climate model projections indicate over 7ºF (3.9ºC) in additional warming under a high emissions scenario, whereas the lowest emission scenario produces less

Figure 1. Global observations and projections of average surface temperature

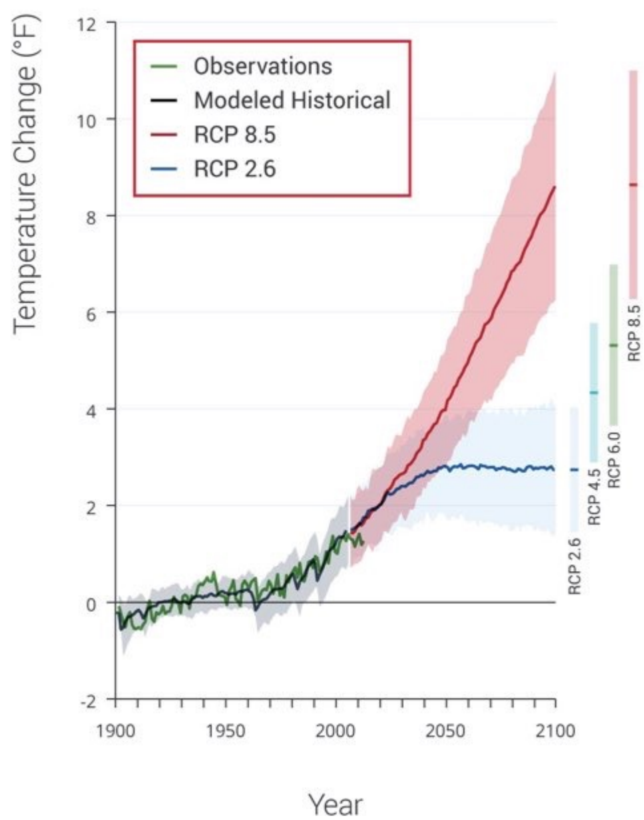


Figure 1. Observations and climate modeling results illustrate 20th and 21st century global average temperature. For historical periods, climate models largely reproduce observed conditions. For future projections, two greenhouse gas emissions scenarios are considered: a low emissions scenario, called RCP2.6 (in blue) and a high emissions scenario called RCP8.5 (in red). End-of-century temperature projections for two middle of the road scenarios, RCP4.5 and RCP6.0, are indicated to the right of graph. Under any scenario, temperatures continue to increase beyond present day levels. Additional end-of-century results for other emissions scenarios are provided to the right. Shading indicates the range of results provided by the ensemble of models. Source: Melillo et al. 2014.

than 2ºF (about 1.1ºC) in additional warming. However, it is important to note that achieving the low emissions scenario would require negative emissions later this century. While both scenarios will result in climate-related impacts, the magnitude of those impacts is likely to vary greatly depending on the trajectory of actual emissions over the coming century. As of 2014, the world continues to closely track the highest emissions scenario (RCP8.5).

Around the world, the impacts of climate change are already underway, affecting agriculture, human health, ecosystems on land and in the oceans, water supplies, and the livelihoods of more vulnerable populations. Future additional impacts along these lines are expected, and therefore, considering options for climate preparedness is now occurring at local, regional, national, and international levels.

Aspen's climate is changing

Observations of Aspen's climate since 1940 indicate rising temperatures and lengthening summers. Minimum temperatures have increased more than maximum temperatures, while average temperatures have increased approximately 2ºF (1.1ºC). One of the most striking indicators of Aspen's changing climate is the trend in frost free days, where the length of the frost free period has increased by 23 days since 1980 (see Figure 2).

Figure 2. Frost free days in Aspen

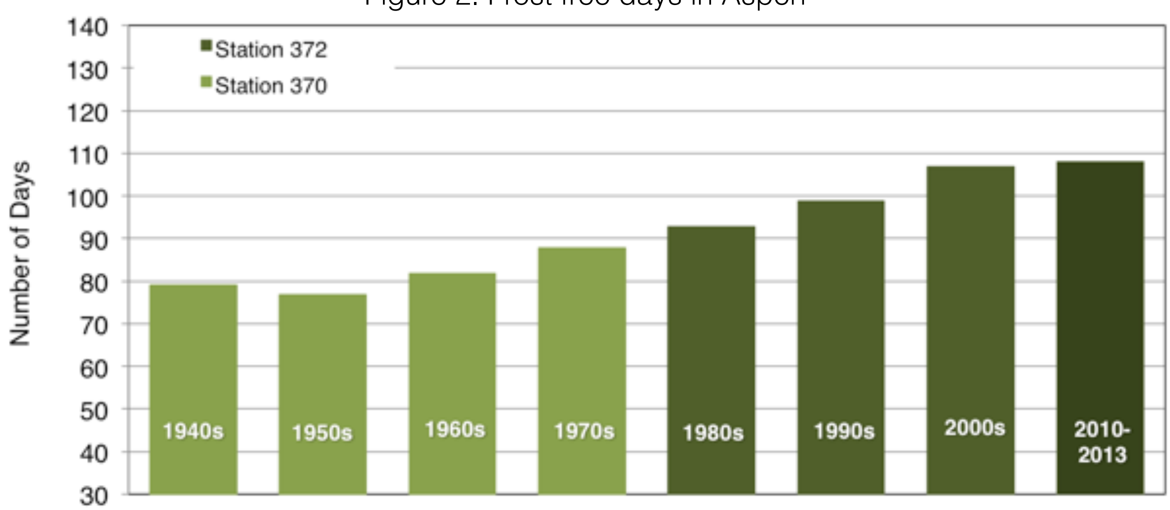


Figure 2 shows a rise in the decadal average of consecutive frost free days since the 1940s. The final darkest green bar does not represent a full decade; it represents only the decade to date: 2010-2013. The location of Aspen's weather monitoring station changed between 1979 and 1980, shifting upward in elevation ~200 feet. Data source: NOAA-NCDC Aspen Stations 370 and 372.

Trends in total precipitation as well as snowfall are mixed, both revealing an overall increase since 1940 yet a slight decrease since 1980. Analysis of local climate trends is somewhat confounded by the relocation of Aspen's primary weather station in 1980 and the high variability associated with single station records.

Table 1. Summary of climate trends observed in and around Aspen

Observation	Trend: 1940-1979	Trend: 1980-2013
Average Temperature	1.0° F increase (.6° C)	1.4° F increase (.8° C)
Frost Free Days	11 day increase	23 day increase
Total Precipitation	2.6 inch increase	0.6 inch decrease
Snow Water Equivalent *(Independence Pass)*	*Data not available*	1.2 inch decrease

Table 1. Trends for the periods 1940-1979 and 1980-2013 are displayed based on data from Aspen's weather station. As explained in further detail in Chapter 2, Aspen's weather station relocated in 1980 approximately 200 feet up in elevation, which may affect the trends observed since 1940. Sources: NOAA-NCDC stations 370 and 372; NRCS SNOTEL Independence Pass.

Additional changes are projected

Future projections of the Aspen region indicate further increases to temperature. Model projections of precipitation are more uncertain, but recent results suggest slight increases. However, due to temperature increase a greater proportion of precipitation is likely to come as rain rather than snow, with repercussions for water availability. A key uncertainty in estimating the magnitude of future changes and their impacts is the quantity of future global greenhouse gas emissions produced by the global economy.

Currently, the world continues to follow a high emissions trajectory. Under this scenario (called RCP8.5), projections prepared for this report for the Western Slope region, including much of the Colorado plateau, suggest a nearly 3ºF (1.7ºC) temperature increase by 2030 and a nearly 10ºF (5.6ºC) temperature increase by 2090, relative to observations during the historical period 1980-1999. These projections are consistent with a similar analysis for the entire state of Colorado. In comparison, a switch to a middle emissions (RCP4.5) scenario could reduce projected temperature change by the end of the century by nearly half.

While aggressive emissions reductions may forestall possible catastrophic changes to Aspen's climate, there are still significant changes anticipated under assumptions of lower emissions. In other words, Aspen's climate is projected to change even with the more optimistic emissions scenarios. As a consequence, building resilience to the impacts of climate change (i.e.

adaptation) is now a prudent complement to existing efforts to reduce emissions (i.e. mitigation) for all likely future pathways.

Model projections of precipitation prepared for this report suggest a slight increase in total precipitation is likely for the Western Slope region during the 21st century. Conclusions drawn from a survey of other modeling results for the surrounding region published since 2006 remain mixed. Some results lean towards greater precipitation, others less, and all results contain uncertainty bounds that include the possibility for either greater or less than historical amounts of precipitation. While projections of precipitation remain uncertain in terms of the overall direction of change, there is high confidence that within the given magnitude (plus or minus) of modeled precipitation projections, rising temperatures will have a drying affect on local hydrology regardless.

Aspen's climate is projected to change under both low and high emissions scenarios. Resiliency planning is relevant for either pathway.

From a planning standpoint, resource managers will need to take into account the uncertainties associated with precipitation projections. Even within these uncertainties, planning efforts can count on the relative likelihood that future precipitation will increasingly come as rain rather than snow, increased temperatures will accelerate drying, and inter-annual variability—long a condition of the Roaring Fork Valley and the broader U.S. West—will persist.

Table 2. Summary of temperature projections for western Colorado

Projection Period	**Medium Emissions (RCP 4.5)** Temp. Change in Deg F (Deg C)	**High Emissions (RCP 8.5)** Temp. Change in Deg F (Deg C)
2030	+2.8 (1.6)	+2.9 (1.6)
2060	+4.5 (2.5)	+6.2 (3.5)
2090	+5.3 (3.0)	+9.7 (5.4)

Table 2. Projections of temperature change relative to the period 1980-1999 are provided for medium (RCP4.5) and high (RCP8.5) emissions scenarios. More results are discussed in Chapter 3, and additional discussion of methods and additional results are available in Appendix B. Source: C. Tebaldi.

Climate impacts could range from incremental to transformational

Climate change will impact a broad range of sectors vital to Aspen's economic, ecological, and cultural well-being. For this report, impacts to recreation and tourism, water, ecosystems, energy, public health and safety, and the built environment are considered.

Table 3. Summary of potential climate impacts to Aspen by sector

	Climate-related changes	Potential impacts
Recreation & Tourism	• Increasing wintertime temperatures • Shift toward more precipitation falling as rain • Increasing stream temperature • Changes to timing and quantity of runoff	• Difficulty achieving targeted ski area conditions during existing ski season schedule • Reduction in suitable fall and early winter conditions for snowmaking • Alterations to timing of ideal summer and winter recreation conditions • Degraded aesthetic quality of environment and increasing hazards posed to visitors (e.g. fire)
Water	• Increasing dry periods in the Western U.S. • Decreasing proportion of precipitation falling as snow • Changes to the timing and availability of water	• Greater pressure on existing water resources • Changes to ecological regimes • Increased fire risk • Changes to timing and volume of peak flows • Reduced hydroelectric generating potential
Ecosystems	• Increasing length of frost free period • Alterations to the timing and type of precipitation • Increasing annual and seasonal temperatures • Alterations to snowpack timing, quantity, and areal coverage	• Plant communities shift to higher elevations • Local specialist species diminish or disappear • Encroachment by invasive species • Enhanced conditions for outbreaks of insects affecting trees • Enhanced conditions for more frequent, more intense, and larger wildfires • Alterations to water quality
Public Health & Safety	• More extreme high temperatures and higher average temperatures • Higher risk of extreme events (e.g., flood, drought, fire, landslide) • Air quality impairment such as increased presence of ground level ozone	• Changing ranges of disease-carrying species • Changing climate conditions correlating to areas of food or water supply • Environmental-stress related mental illness • Loss of property or injury related to disaster events • Lengthened and growing allergy season • Increased respiratory illness
Energy	• Increasing high temperatures during summer • Warming of wintertime minimum temperatures • Alterations to snowpack and timing and quantity of runoff	• Uncertainty in future dependability of hydropower resources • Increase in cooling load and reduction in heating load of building's energy demand • Climate-related risks to national and international energy supply
Infrastructure & the Built Environment	• Shift in the magnitude of temperature and precipitation extremes • Warming of wintertime minimum temperatures; increase in summertime maximum temperatures • Alterations to timing and quantity of runoff	• Increase in hazards to structures and infrastructure from flood, fire, landslide and drought • Increase in cooling load and reduction in heating load of buildings' energy demand

This report draws upon local observations and regional projections, as well as relevant scientific literature, to discuss the types of potential impacts that may occur in the Aspen area. However, specific responses are beyond the scope of this report and will require more detailed investigation into location-specific risks and strategies for their reduction. One example is the need to update studies on landslide risk based on projections of future hydrologic patterns — such as the rate of snowmelt and frequency and intensity of heavy rain events.

Some of the impacts identified in this study may take place gradually over decades, such as changes in energy demand patterns by people or gradual uphill shifts in plant and animal species. Other impacts, such as a severe fire or a precipitation event that causes a flooding or mudflow event could occur suddenly with dramatic and immediate consequences. Uncertainties remain in both areas, including the pace at which the global economy will decarbonize and the sensitivity of the global climate system to increasing concentrations of greenhouse gases in the atmosphere.

Vulnerability to these global changes at a local level, in turn, will depend on how local climate is affected by larger regional and global patterns. In addition, site-specific conditions, such as the exposure of structures to fire or the capacity of emergency response in event of a flood, are relevant for evaluating risk and prioritizing potential response strategies.

Ongoing consideration of all of the aforementioned components of local impacts assessment are needed as Aspen plans, implements, evaluates, and adjusts its response to both near and long-term impacts of climate change.

Stakeholders are concerned and have begun to prepare

As a preliminary source of input from the Aspen community, AGCI and the City of Aspen interviewed eleven stakeholders representing the spectrum of sectors considered in this report. Interviews were designed to elicit stakeholders perspectives on climate change, such as personal observations of changes, impacts identified, actions contemplated or taken in response, and overall level of concern about climate change relative to other issues.

All stakeholders surveyed were able to identify changes in the environment they found to be significant, although many were uncertain as to the extent the alterations were caused by climate change. Perceived changes identified by stakeholders included:

- More common drought conditions
- Less predictable seasonal weather patterns
- Earlier onset of spring
- Decreasing winter snowpack
- Reduction in extreme cold winter temperatures
- Species shifts in plant and animal communities

In general, stakeholders interviewed for this study were already involved in efforts that in some way, whether or not specifically focused on climate change, relate to reducing vulnerability or enhancing resiliency. These efforts include:

- Watershed planning and riparian health management (i.e. Roaring Fork Watershed Plan)
- Enhancing operational speed and flexibility for snowmaking
- Mitigating wildfire hazard and wildfire response capacity
- Implementing greener building codes
- Adjusting timing, size, and location of commercial rafting trips
- Expanding attractions for tourists during early winter and shoulder seasons

In addition, numerous areas of activity were identified by stakeholders for potential future actions, whether taken independently or in collaboration with other entities. These desired future actions include public education, enhanced flexibility in planning and action (e.g., development of crisis plans), reconsideration of water laws, long-term monitoring, and adjustment of building codes in relation to fire protection and energy use.

Moving forward on resiliency planning

> **Resilience:** *The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event or gradual system change in a manner timely enough to ensure the preservation, restoration, or improvement of its essential basic structures and functions.*- Adapted from IPCC 2012

To build resilience in the face of the complex nature of climate change requires an iterative, community-based process of assessment, planning, implementation, and evaluation. While elements of this cycle have occurred in the past, this phase of Aspen's engagement with resiliency planning represents the green circle in Figure 2. This type of process and its resulting outcomes are strengthened by engagement with a broad base of stakeholders, including those who may be impacted by actions taken as well as those who can inform and implement responses strategies. A diversity of criteria and types of responses can be considered in this process, and lessons from other communities may prove helpful in navigating the path forward.

Figure 3. Adaptation planning cycle

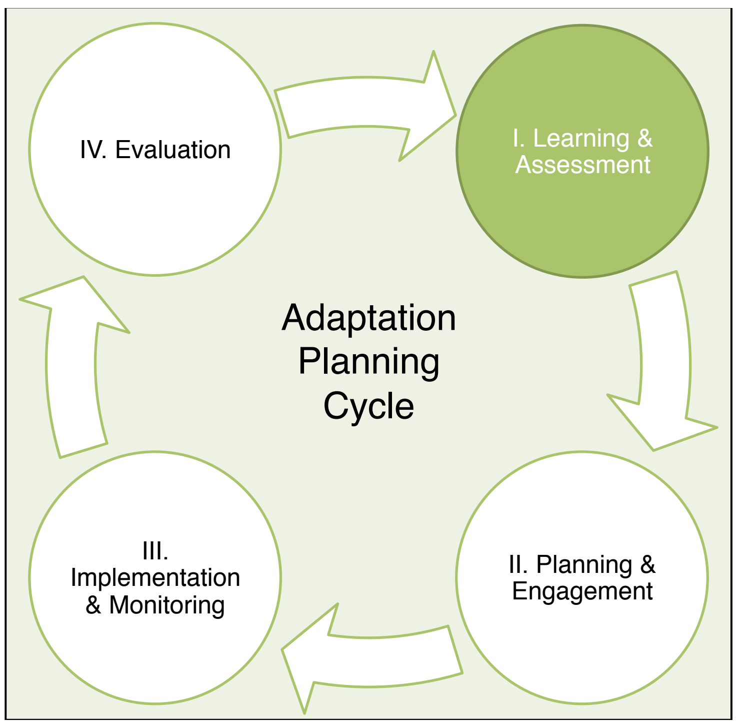


Figure 3. Planning in the context of change is often best supported by an adaptive planning process that is cyclical rather than linear and allows for learning and adjustment along the way. Initial learning and assessment (I) informs planning and initial engagement with the community (II). Plans are then implemented and long-term monitoring based on goals and objectives (III) enable evaluation. As learning takes place within the sectors of our community — what worked, what didn't, and why — the adaptive management cycle begins anew, building from refined goals of and approaches to resiliency and sustainability.

Figure 3 presents an idealized version of the adaptive planning process as four phases. Though in practice resiliency planning may not occur as neatly as illustrated here, the notion of planning as a cyclical process instead of as a linear route with beginning and end points is a central theme of effective resiliency planning in the context of climate change.

As a resiliency planning process begins to contemplate actions and the goals that impel them, a range of types of response can be considered along with multiple criteria for gauging success. For example, responses to the impact of increasing wildfires could include reducing exposure of assets in fire prone areas, reducing the vulnerability of structures through best practices in wildfire mitigation, enhancing emergency response and recovery capacity, or a combination of all these approaches as well as others. Response strategies under the category of *transformation* may include a number of resiliency enhancing actions coordinated with efforts such as greenhouse gas reduction goals that, in combination, increase the overall sustainability of a community.

Criteria for success can be considered throughout resiliency planning and can cover a broad range of factors, including the avoidance of economic losses and preservation of basic municipal services. Criteria can also extend to capture important, if harder to measure, factors such as maintaining ecological health, preserving procedural integrity, and maintaining or even enhancing community character and culture (see Table 4).

Table 4. Categories of response and criteria for success

Example Categories of Response	Example Criteria for Success
• **Reduce exposure:**(e.g., relocate assets from high risk areas) • **Enhance response and recovery preparedness** (e.g., increase emergency response capacity) • **Increase resilience to changing risks** (e.g., planning for multiple future scenarios) • **Reduce vulnerability** (e.g., hardening infrastructure and services to extreme events) • **Transfer and share risks** (e.g., collaborative planning and action with stakeholders and neighboring governments) • **Transformation** (e.g., pursing an integrated approach to mitigate underlying causes of risk while also enhancing resiliency and overall sustainability)	• **Economic:** Minimizing or avoiding financial losses and/or capitalizing on opportunities and benefits • **Institutional**: Preserving the ability of institutions, policies, and resource management to meet obligations to constituents as well as ecosystems • **Ecological:** preserving the resilience capacity, diversity and services made possible by healthy ecosystems • **Social:** Reducing vulnerabilities and/or inequities within marginalized populations while strengthening communities • **Procedural:** Supporting transparent and inclusive processes • **Cultural:** Preserving and/or enhancing vital aspects of community character and civic culture
Adapted from IPCC 2012	*Adapted from Moser and Boykoff 2013*

Communities large and small have begun considering and implementing actions to enhance resiliency. Examples range from Keene, New Hampshire to King County, Washington — from New York City to Moab, Utah. In many instances, exemplary plans include inclusive processes for community input, a scientific basis for considering future impacts, specific action items that delineate responsibilities, timelines, and measurable outcomes, as well as opportunities for reflection and flexibility as future conditions unfold over time.

Additionally, regional and national networks and organizations have formed to provide resources to support communities in their efforts. Chapter 6 of the report offers more details and descriptions of these resources. Leadership as well as partnerships plays an important role in developing and implementing resiliency strategies. Aspen is in a position to demonstrate leadership in adaptation strategies for mountain resort communities.

Roadmap

The full report examines the key points and statements made throughout this summary in greater depth. Chapter 1 outlines the rationale for the update to the 2006 report and provides a conceptual overview of assessing climate-related risk at a local scale. Definitions pertinent to thinking and communicating about preparedness for climate change are provided.

Chapter 2 presents observational data on recent historical patterns of climate change for the world, the southwestern region, and for Aspen. A specific analysis of available Aspen weather data since 1940 is reported in addition to a brief discussion of historical hydrologic data on the Roaring Fork River. As a complement to historical observations, Chapter 3 looks forward by using several lines of climate modeling results to portray possible future climate conditions in the Aspen region based on various greenhouse gas emissions scenarios. One approach taken employs a similar methodology to those utilized in the 2006 Study. Another approach characterizes the results of modeling studies for regions surrounding or near to Aspen and compares these new results to the results of the 2006 Study.

Chapter 4 explores the potential impacts to six sectors identified as important to the City of Aspen while setting of the scope of this study. They include: recreation and tourism, water, ecosystems, public health and safety, energy, and infrastructure and the built environment. The impacts presented in this section are based on a survey of scientific literature addressing climate-related impacts in areas comparable or related to Aspen. It is anticipated that this overview will be a launching pad for more in-depth consideration of how anticipated trends and changes will play out locally.

Chapter 5 summarizes the input received from a set of eleven stakeholder interviews conducted in early 2014 by AGCI and the City of Aspen. Stakeholders were selected to represent the range of sectors examined in Chapter 4, and the interviews were intended as a preliminary round of engagement with the community on climate change impacts and resiliency planning. Summaries of changes and impacts identified by stakeholders as well as actions taken or in planning are documented and discussed.

Chapter 6 offers some preliminary guidance for the anticipated City and community effort on building resiliency. A conceptual model for adaptive management, categories of response that build resiliency, criteria to consider when defining goals and objectives, and a small set of helpful examples are provided. Finally, a concluding section points the way forward and identifies areas of future research that could support a resiliency planning process.

Many of the climate impacts and vulnerabilities discussed in the 2006 report related to climate change impacts on the physical, socioeconomic, and ecosystems of the Aspen area have been validated in the literature on Upper Colorado River basin and mountain resort communities in general. This new study, however, shifts its focus towards resiliency and how to frame it in a changing climate as a critical complement to ongoing mitigation efforts. It serves as an introduction to areas the City and the community as a whole may consider in developing a comprehensive resiliency plan — a living document updated as conditions change and new information becomes available.

CHAPTER I: INTRODUCTION

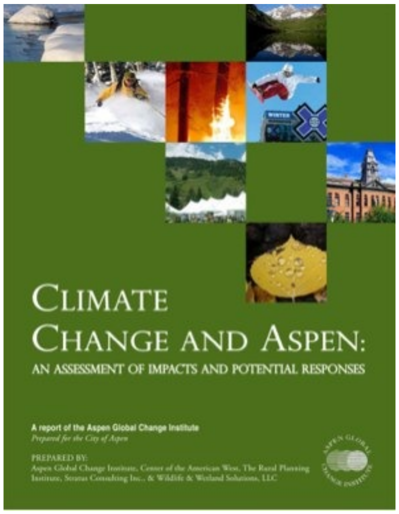
Aspen's climate is already changing, and even greater change is anticipated in the future. Although future climate-related societal and ecological impacts in Aspen cannot be identified with complete certainty, they are likely to range from significant to severe and touch a broad range of sectors critical to Aspen's economic and cultural livelihood.

Preparing for potential changes in ways that enhance resiliency and reduce vulnerability to identified risks can enhance the overall sustainability, vitality, and prosperity of a community. As a result, steps taken toward resiliency planning, along with continued leadership in implementing greenhouse gas emission reductions, offer hope that Aspen's unique environment and culture will continue to be deeply appreciated and highly valued by residents and visitors alike.

Aspen's climate is changing and will very likely continue to change, with important implications for the community's resiliency and preparedness

The following report—*Climate Change and Aspen: An Update on Impacts to Guide Resiliency Planning and Stakeholder Engagement*—represents a fresh assessment of science and practice relevant to the City's commitment to climate resiliency planning. This report builds upon a study prepared for the City by AGCI in 2006 entitled: *Climate Change and Aspen: An Assessment of Impacts and Potential Responses* (hereafter referred to as the "2006 Study").[4] The 2006 Study was a larger effort that explored more in-depth the potential impacts of climate

[4] Aspen Global Change Institute. 2006. Climate Change and Aspen: An assessment of impacts and potential responses. Available at: http://www.agci.org/dB/PDFs/Publications/2006_CCA.pdf



change, with a focus on snow availability for skiing and its direct and indirect effects on the local economy. This 2014 report presents a broader assessment of impacts across multiple sectors, though not in the same level of detail as applied to the specific sectors examined in 2006. A summary of results from 2006 is provided as Appendix A of this report.

Rationale for 2014 update

A placeholder to consider options for climate adaptation was included as part of the City of Aspen's Climate Action Plan adopted in 2007. Focused attention on this component started in 2012 as part of discussions among City staff and members of the Aspen Global Warming Alliance (AGWA). In August 2013, during a summer retreat, the Aspen City Council identified development of a climate change resiliency plan as one of its top 10 goals for the coming year.

To inform this work, the City has engaged AGCI to identify important updates in the science pertaining to climate change impacts in the Aspen area and to consider a wider range of impacts that are relevant to local resiliency plans and practices. The intention of this report is not to recommend specific actions or to be prescriptive about adaptation strategies, but rather to provide a context for dialog within the City departments, staff, and the community on building resiliency in the context of climate change. These ongoing discussions will in some cases provide the basis for further studies to provide more detailed information — for example on municipal water availability or risk to people and property from area landslides in an altered climate.

Definitions and concepts

As a prelude to the chapters that follow, several useful definitions and concepts for considering the dimensions of climate-related risk at a community scale are presented.

Climate variability and change – Climate refers to the average conditions of weather, such as air temperature and precipitation. Drivers of change in climate include natural variability and human contributions at global and local scales. For basic information as well as details about the scientific basis of climate science, impacts from climate change, and possible solutions, we recommend a series of reports published by the United Nations Intergovernmental Panel on Climate Change (IPCC 2013, 2014). For each of these reports, a summary for policy makers is provided.[5] Additionally, a U.S.-focused report—the Third National Climate Assessment—provides similar background material on climate science as well as region-by-region and sector-by-sector analysis of domestic climate change impacts.[6]

Vulnerability – The degree to which a system—for example, a city, business, or ecosystem—is likely to experience harm due to exposure to a hazard, either a perturbation or a stressor.[7]

Adaptation – Actions throughout society—by individuals, groups, and/or governments—in response to actual or expected climatic impacts, which reduce harm or exploit beneficial opportunities.[8] Adaptation can be reactive to an abrupt or gradual change, or it can anticipate these changes and adjust accordingly using best available information.

Resilience – The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event or gradual systemic change, in a manner timely enough to ensure the preservation, restoration, or improvement of its essential basic structures and functions.[9]

Risk - The likelihood of significant alterations in the normal functioning of a community due to hazardous physical events or long term changes that lead to adverse human, material, economic, or environmental effects.[10] A component of risk is existing societal capacity to absorb, cope with, or respond to hazards and impacts

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5 For the latest Intergovernmental Panel on Climate Change (IPCC) series of assessment reports go to: www.ipcc.ch. The last comprehensive assessment report produced by the IPCC was the Fifth Assessment Report (AR5) completed in 2014, which include summaries for policy makers.

6 Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014. Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program: 841. doi:10.7930/J0Z31WJ2. http://nca2014.globalchange.gov/

7 Turner, B. L., R.E. Kasperson, P.A. Matson, J.J. McCarthy, et al.. 2003. A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the United States of America* 100 (14): 8074–9. doi:10.1073/pnas.1231335100

8 Adger, Neil, N.W. Arnell, and E.L. Tompkins. 2005. Successful adaptation to climate change across scales. *Global Environmental Change* 15 (2): 77–86. doi:10.1016/j.gloenvcha.2004.12.005

9 IPCC. 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, et al. (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

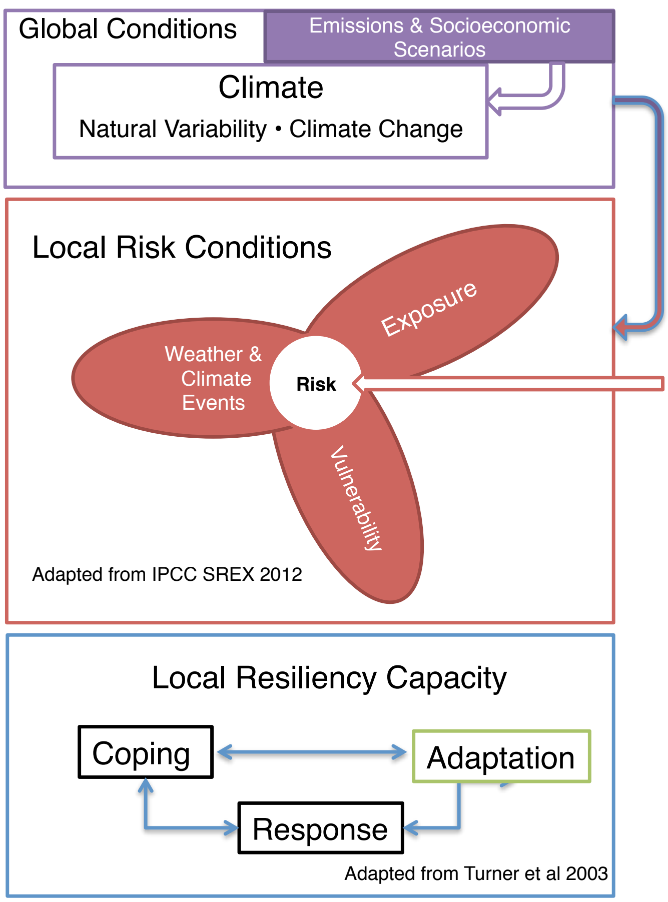
10 Ibid., 2012.

when they occur. Responses to reduce risk may include proactive and reactive strategies, such as reducing exposure and vulnerability prior to events or changes, or increasing capacity to respond to and recover from events when they do occur.

Conceptualizing climate risk

Evaluating and preparing appropriate responses to climate-related risk at community levels involves looking at a complex set of physical, societal, and ecological conditions and future trends at both global and local scales — in the context of: place, the built environment, and social constructs such as households, neighborhoods, and municipalities. To do this well involves ongoing collaboration between decision-makers, planners, stakeholders, and

Figure 1.1 Assessing local climate-related risk



Global conditions, including natural variability and human-driven climate change, drive local weather and climate-related events and trends

Climate-related *risk* is more than the likelihood of occurrence of potentially hazardous events: risk is a confluence of factors (e.g. fire), exposure to that event, and vulnerability due to that exposure.

Local resiliency capacity helps reduce risk and involves coping and response capacity as well as the ability to adjust in ways that reduce vulnerability and exposure to conditions in the future.

Figure 1.1 describes the relationship between global conditions and local risk and resiliency. Projections of future climate rely upon scenarios of future greenhouse gas emissions and their effect on the climate from global to local scales. The risk to society depends on local exposure and vulnerability to those conditions. Local resiliency capacity which includes coping, response, and adaptation can help manage and even reduce that risk.

researchers.[11] Figure 1.1 provides a conceptual model for how global climate conditions relate to local risk conditions and how local resiliency can support risk management and reduction.

Making sense of climate-related risk
(see Figure 1.1)

- Global conditions, including natural variability and human-caused climate change, largely drive the weather and climate-related events and trends that occur locally.
- Climate-related risk is a confluence of hazard type (e.g. fire, drought), exposure to such an event or trend, and vulnerability to that exposure.
- Local resiliency capacity involves existing coping and response capacity as well as the ability to proactively adapt in ways that reduce vulnerability and exposure to conditions in the future as well as enhance response mechanisms for different temporal and spatial scales.

Whereas local mitigation actions, such as reducing greenhouse gas emissions, can only minimally abate the future trajectory of global climate change, adopting and implementing adaptation strategies has a large potential to increase local resiliency and, as a result, reduce risk. Mitigation at the community level, however, is still critical in placing community actions in line with the Aspen Climate Action Plan and can have an outsized effect in demonstrating mitigation pathways that resonate with other communities and national audiences. Of course, the more communities around the world that take mitigation seriously, the lesser the impact of climate change.

[11] Moser, Susanne and Maxwell Boykoff, ed. 2013. Successful Adaptation to Climate Change: Linking Science and Policy in a Rapidly Changing World. 1st ed. New York: Routledge.

CHAPTER 2: HISTORICAL OBSERVATIONS

Global & regional trends

Temperatures in Aspen—as well as the region of the Southern Rockies—are on the rise. These trends mirror pronounced global rises in temperature that continue to be reaffirmed and updated by ongoing research. Most notably, in 2013, the International Panel on Climate Change (IPCC) Fifth Assessment Report examined updated evidence from climate observations and concluded:

> Warming of the climate system is unequivocal, and…many of the observed changes are unprecedented over decades to millennia.
>
> IPCC Working Group I Summary for Policy Makers, 2013

Global temperatures have risen sharply, particularly since the 1970s. Multiple lines of evidence have enabled scientists to attribute these changes, with high confidence, to use of fossil fuels and other human activities that produce greenhouse gases or alter land use. The trend over the past 130 years, between 1880 and 2012, depicts average surface temperature across the Earth as rising 1.5°F (0.8°C). An increase of 1.3°F (0.7°C) is observed from 1950-2012 (see Figure 2.1).[12]

U.S. national temperatures and regional temperatures in the Southwest, including Colorado, are also increasing, currently at a rate that surpasses the global rate of change. National temperatures rose approximately 2.0°F (1.1°C) between 1978 and 2008. The state of Colorado

[12] IPCC, 2013. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

has shown a similar pattern, where average temperatures across the state of Colorado have increased by approximately 2°F (1.1°C) from the 1980's to present and by 2.5°F (1.4°C) since the 1950s.[13]

Nationally, changes in precipitation as a response to global warming vary by region, with some areas seeing a decrease and other areas seeing an increase.[14] Many regions have experienced levels of annual precipitation similar to their historical averages but have experienced an alteration in the timing or intensity of events.[15]

Figure 2.1 Observational record of annual mean temperature: Global, U.S., and Colorado

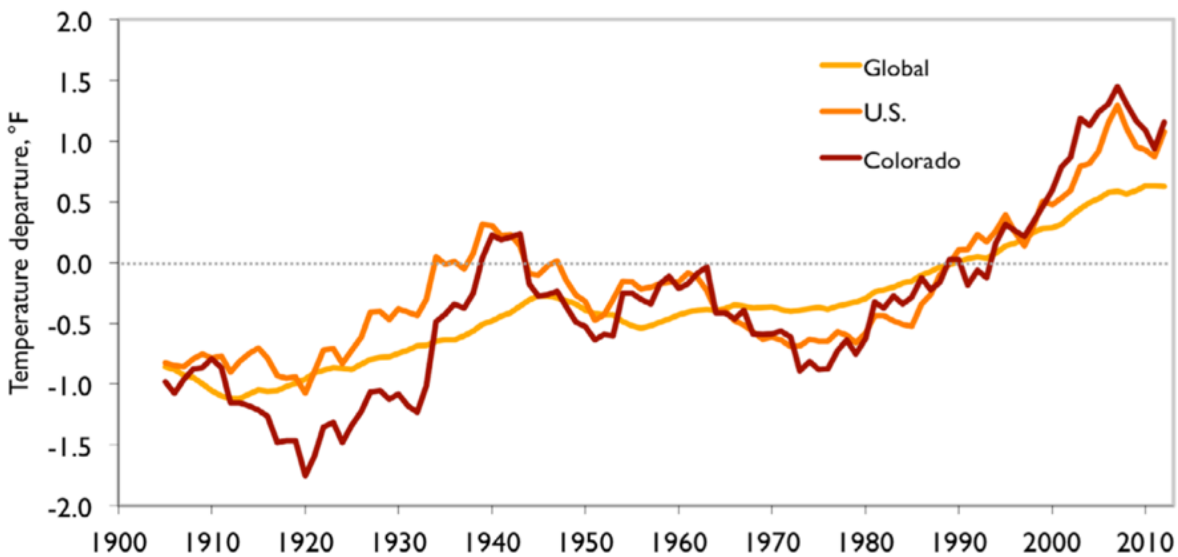


Figure 2.1 shows the observational record from 1895-2012 of annual mean temperature at three different scales: for the globe, the U.S., and Colorado. The lines of the graph are smoothed over a 10-year running average and the temperature baseline from which departure is shown (represented by the gray dotted line) represents the 1971-2000 average. Source: Colorado Water Conservation Board (Lukas et al. 2014).

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[13] Lukas, J., J. Barsugli, N. Doesken, I. Rangwala, and K. Wolter. 2014. Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation**.** A Report for the Colorado Water Conservation Board. Western Water Assessment.

[14] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program: 841. doi: 10.7930/J0Z31WJ2.

[15]Gao, Y., L. R. Leung, J. Lu, Y. Liu, M. Huang and Y. Qian. 2014. Robust spring drying in the southwestern U.S. and seasonal migration of wet/dry patterns in a warmer climate. *Geophysical Research Letters* 2014 GL059562.

2.2 Colorado annual precipitation, 1900-2012

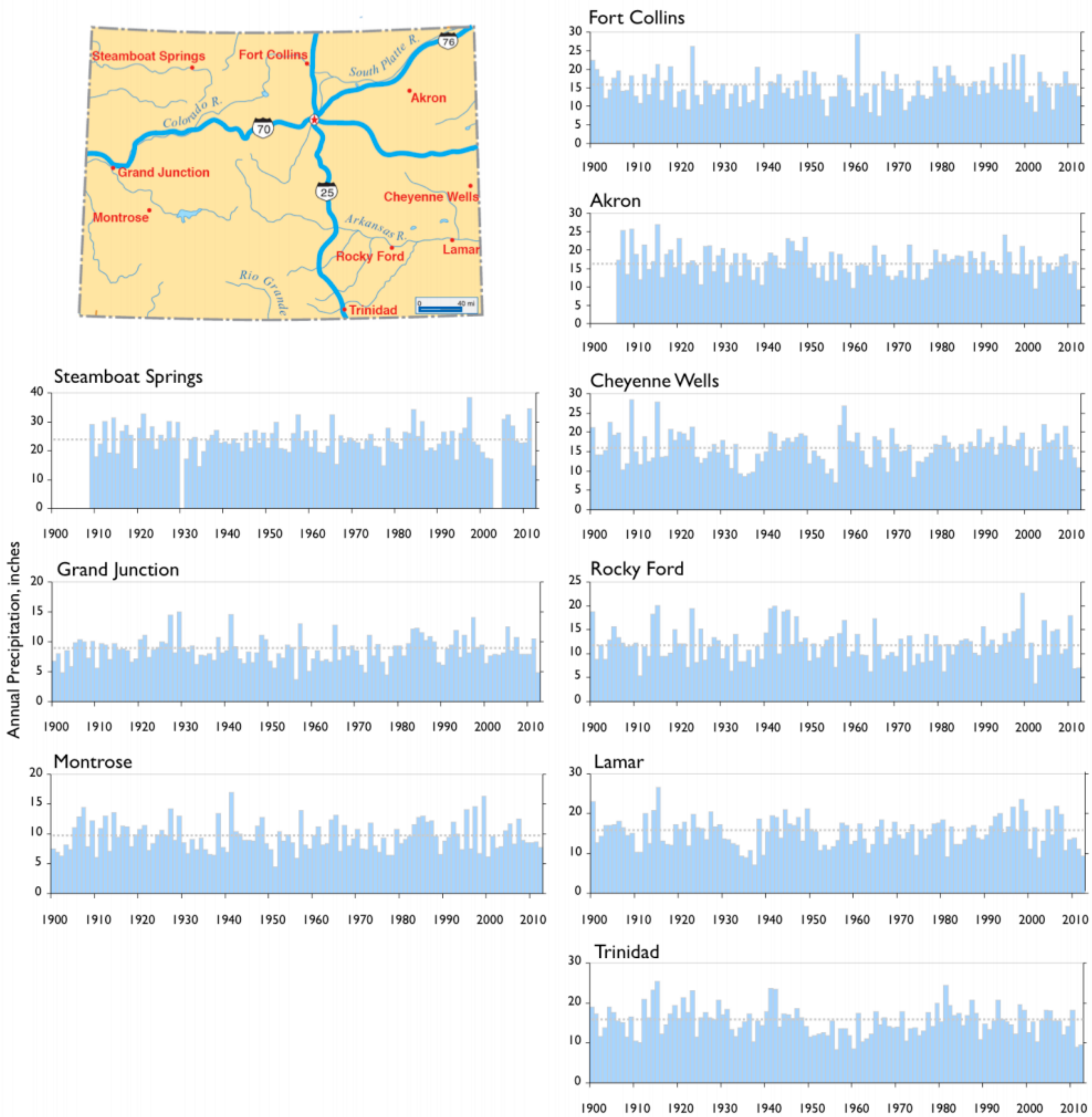

Figure 2.2 shows precipitation across the state of Colorado at 9 monitoring locations since 1900. The thin, dotted lines for each data set shows the average precipitation for 1971-2000. For each station no significant trend is identified for precipitation at 30-, 50-, or 100-year timescales. Source: Colorado Water Conservation Board; Lukas et al. 2014.

Colorado's statewide precipitation record from the NOAA database shows inter-annual variability but no noticeable trend of increase or decrease over the last century (Figure 2.2). The 2014 report *Climate Change in Colorado*, prepared by the Western Water Assessment, found no significant trend in annual precipitation across nine representative stations statewide since the 1900s, nor has there been a trend in droughts over this same time period. Historical proxies for water availability such as tree rings reveal that previous to the start of the 20th century, there were occurrences of droughts in Colorado of longer duration and greater severity than those seen in the past 100 years, indicating such mega-droughts could occur again in Colorado's future.[16]

Colorado temperatures show a clearly discernible rising trend over the last century (Figure 2.1), and even if overall quantity of precipitation remains about the same in Colorado, warming temperatures can impact the water cycle. This pattern is pertinent to local ecological and hydrological conditions; water availability may decrease even if annual precipitation remains steady or increases slightly.

Research indicates that increased temperatures may impact watersheds by causing increased evaporation, a shift toward a greater proportion of precipitation coming as rain rather than snow, earlier runoff, increased evapotranspiration, and drying of soil during the growing season—all of which have the capacity to diminish ecological water storage and availability.[17]

Water availability is likely to be a matter of future concern even under projections where annual precipitation is expected to remain relatively flat.

Studies of snowpack across the Southwest have indeed noted a shift from snowpack-dominated toward rainfall-dominated water regimes.[18] While the Roaring Fork watershed is likely to remain snowpack-dominated in the future, studies of snowpack in mountain areas suggest that increased temperatures combined with the phenomenon of dust-on-snow events, which decrease albedo and hasten melting, may both contribute to overall decreases in snow cover and accelerated melting rates. Colorado's alterations in snowpack are comparable to trends elsewhere in the Southwest, with one study of the period 1979- 2007 revealing a shift of, on average, 2-3 weeks earlier peak streamflow timing and snowmelt events during the spring.[19]

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16 Lukas et al. 2014.

17 Gao et al. 2014.

18 Barnett, Tim P., David W. Pierce, Hugo G. Hidalgo, Celine Bonfils, et al. 2008. Human Induced Changed in the Hydrology of the Western United States. *Science*, 319 (5866): 1080-1083. doi:10.1126/science.1152538

19 Clow, David W.. 2010. Changes in the Timing of Snowmelt and Streamflow in Colorado: A Response to Recent Warming. *J. Climate* 23: 2293–2306. doi: 10.1175/2009JCLI2951.1

Finally, consideration of climatic and hydrological trends should be considered in conjunction with societal trends in water demand. The Colorado River Basin services 40 million users and spans 7 states and 2 countries. Overall demand for water in the Basin has grown over the last century, and following the 2002 drought, demand for water resources exceeded supply for the first time. Use of the Colorado River is governed by a complex set of legal structures (i.e. the Law of the River). Further information on water supply and demand can be found through an extensive study published by The Bureau of Reclamation in 2012, which provides in-depth analysis of historical trends and future projections.[20]

Local observations

Table 2.1 Summary of Aspen area observations

Observation	Trend: 1940-1979	Trend since 1980
Average, Maximum, and Minimum Temperatures	Average: 1.0°F (0.6°C) *increase* Min: 1.9°F (0.1°C) *increase* Max: 1.2°F (0.7°C) *decrease*	Average: 1.4°F (0.8°C) *increase* Min: 1.2°F (0.7°C) *increase* Max: 1.7°F (1.0°C) *increase*
Frost Free Days	11 day increase	23 day increase
Annual Snow	1.6 inch increase	9.9 inch decrease
Annual Precipitation	2.6 inch increase	0.6 inch decrease
April 1st Snow Water Equivalent*	*Data not available*	1.2 inch decrease

Table 2.1 shows changes over time calculated from the trend line slopes for the duration of each station 's record: from 1940-1979 and from 1980-2013 (Station 372). The 1940-1979 data was gathered from NOAA Station Aspen 370, while the 1980-2013 data is from the Aspen Station's new location at 372, which is ~200 feet higher in elevation. *The data for April 1st Snow Water Equivalent is from the NRCS station located on Independence Pass and does not have data prior to 1980.

Concurrent with national and global trends, average temperatures in Aspen continue to rise, following the same warming direction identified in the 2006 Aspen report. It should be noted that

[20] U.S. Bureau of Reclamation. 2012. Colorado River Basin Water Supply and Demand Study. December 2012. http://www.usbr.gov/lc/region/programs/crbstudy/finalreport/Study%20Report/CRBS_Study_Report_FINAL.pdf

the Aspen record is based on the data of a single weather station. The data are collected by the National Weather Service and are accessible online through the National Climatic Data Center. Single station data tend to show greater variability from year to year than averages of data from multiple stations within a region.

Temperature

Average temperatures in Aspen have risen by 1.4°F (0.8°C) since 1980 compared with an increase of 0.8°F (0.4°C) during a base period of 1940-1969 (Figure 2.3). Using averages during the time 1940-1969 as a base period, the last decade (2004-2013) is 1°F (0.6°C) warmer than the base period average. Importantly, the location of Aspen's weather station changed in 1980

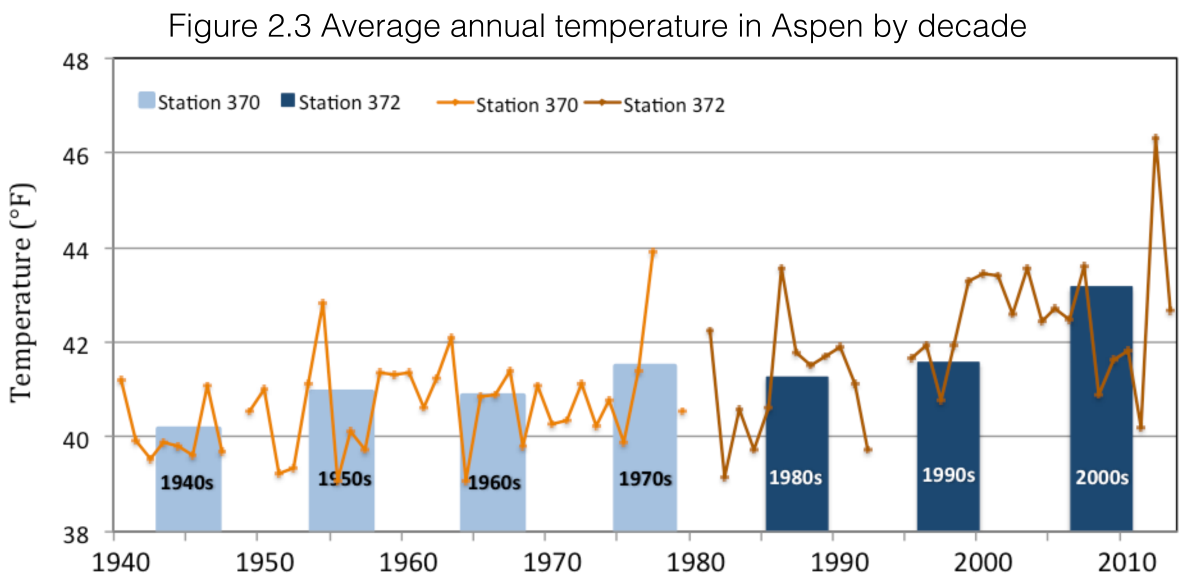

Figure 2.3. The blue bars are decadal averages starting with the 1940s. The orange line is yearly averages. Average annual temperatures in Aspen have increased since 1940. Aspen Station 370 was moved from an in-town location to the Water Treatment Plant and re-designated Station 372 in 1980. The new station, approximately 200 feet higher in elevation, is anecdotally understood to be slightly cooler, but overlapping monitoring records are unavailable to verify this. Data source: NOAA-NCDC Aspen Stations 370 and 372.

to a new location about 200 feet higher and 0.5 miles away from the initial site.[21] Minimum and maximum temperatures observed using data from the Aspen station have behaved differently during the periods considered. Average minimum temperatures have increased across both periods: by 2.7°F (1.5°C) from 1940-1969 and 1.2°F (0.7°C) from 1980-2013. Average maximum temperatures, by contrast, decreased by 1.0°F (0.6°C) between 1940-1969 but rose by 1.7°F (0.9°C) from 1980-2013. This type of trend, where average

[21] Since the record is not continuous, the record prior to 1980 compared to after the station move is somewhat compromised.

minimum temperatures increase more than maximum temperatures has also been observed at larger spatial scales.[22]

Figure 2.4 Observed changes in minimum temperature by season

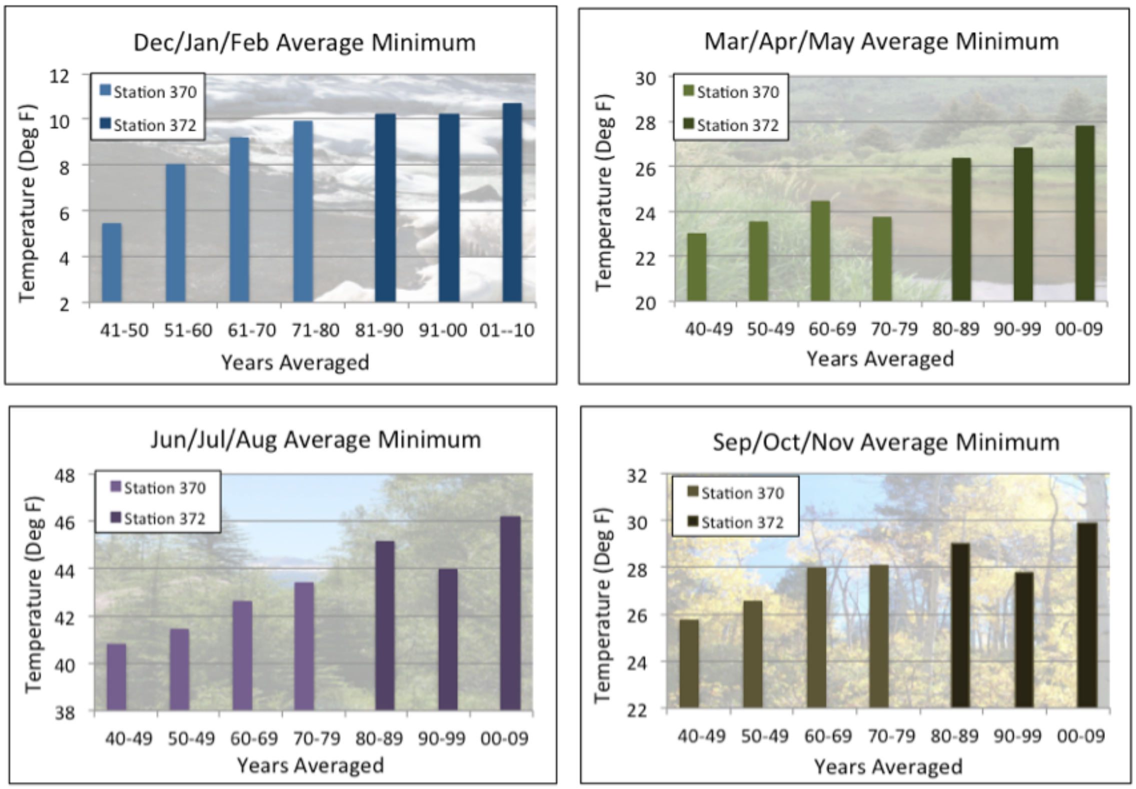

Figure 2.4 shows average minimum temperature by season for each decade since 1940. The winter season is counted as beginning in December of the first year and carrying through continuously to January and February of the following year. The location of Aspen's weather monitoring station changed in 1980, shifting upward in elevation ~200 feet. Data source: NOAA-NCDC Aspen Stations 370 and 372.

The observed trend of increasing minimum temperatures has occurred across all seasons. Understanding seasonality in warming is important because dates of freezing temperatures impact the growing season, bud success, and water availability. Increases in minimums also affect the ability to make snow in November and December. Increases in spring minimum temperatures are of particular importance due to their effect on the timing and pace of snowmelt (Figure 2.4). Increasing minimum temperatures in winter also have impact on snow depth and duration, as they may lead to cold-season precipitation coming as rain rather than snow. In a

[22] Braganza, K., D. J. Karoly and J. M. Arblaster. 2004. Diurnal temperature range as an index of global climate change during the twentieth century. *Geophysical Research Letters* 31(13): L13217.

Figure 2.5 Observed changes in maximum temperature by season

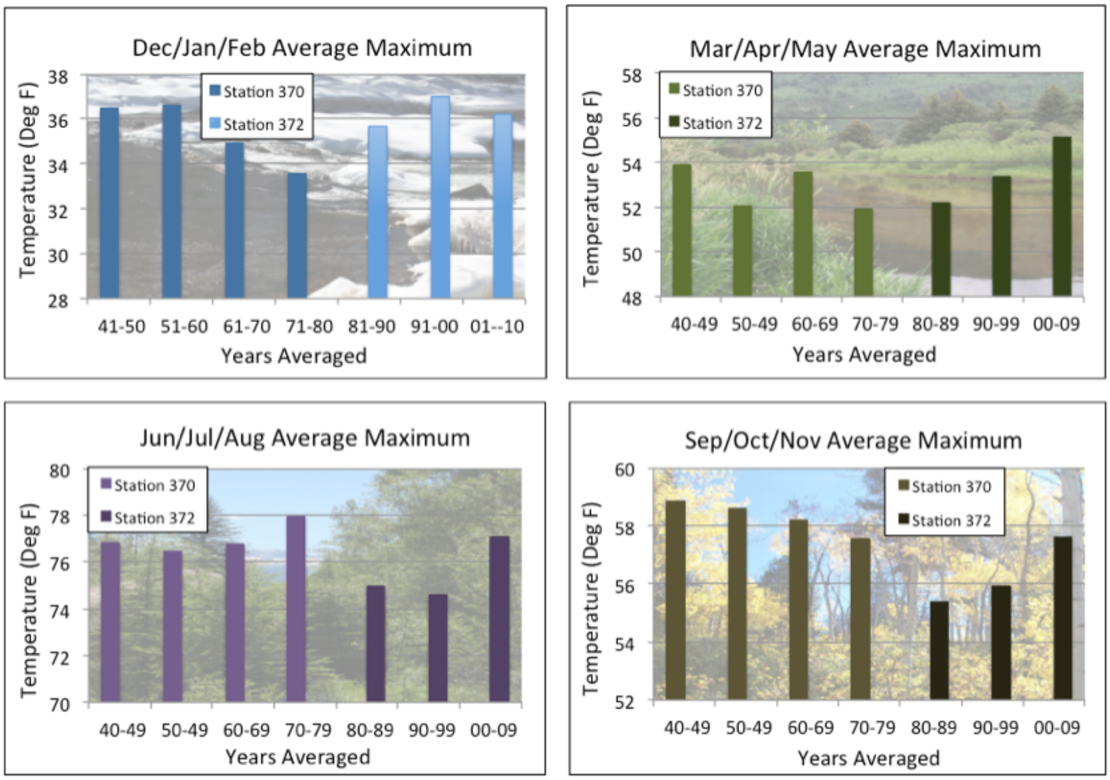

Figure 2.5 shows average maximum temperature by season for each decade since 1940. The winter season is counted as beginning in December of the first year and carrying through continuously to January and February of the following year. The location of Aspen's weather monitoring station changed in 1980, shifting upward in elevation ~200 feet. Data source: NOAA-NCDC Aspen Stations 370 and 372.

snowpack-dominated watershed such as Aspen's a shift from snow to rain during winter will reduced water availability in the following warmer seasons. Generally, maximum seasonal temperatures at the Aspen station showed a less clear pattern since the 1940s than minimum temperatures, with the exception of the spring season. From 1980-2009 maximum temperatures for the spring months show a rise each decade (Figure 2.5).

Observation of warming since the 1940s is especially evident in number of frost free days per year.The last ten years, 2004-2013, showed an average of 30 more frost free days per year than the annual average of the 1940-1969 base period (see Figure 2.6) and an average of 23 more frost free days per year just since 1980 (see Table 2.2). A longer frost free period may offer opportunities in terms of crop production, but it will also alter natural cycles, such as timing relationships between animals and their food sources. Additionally, over time distinct habitats of the valley may change in appearance as vegetation shifts in response to climate conditions.

Figure 2.6 Frost free days in Aspen

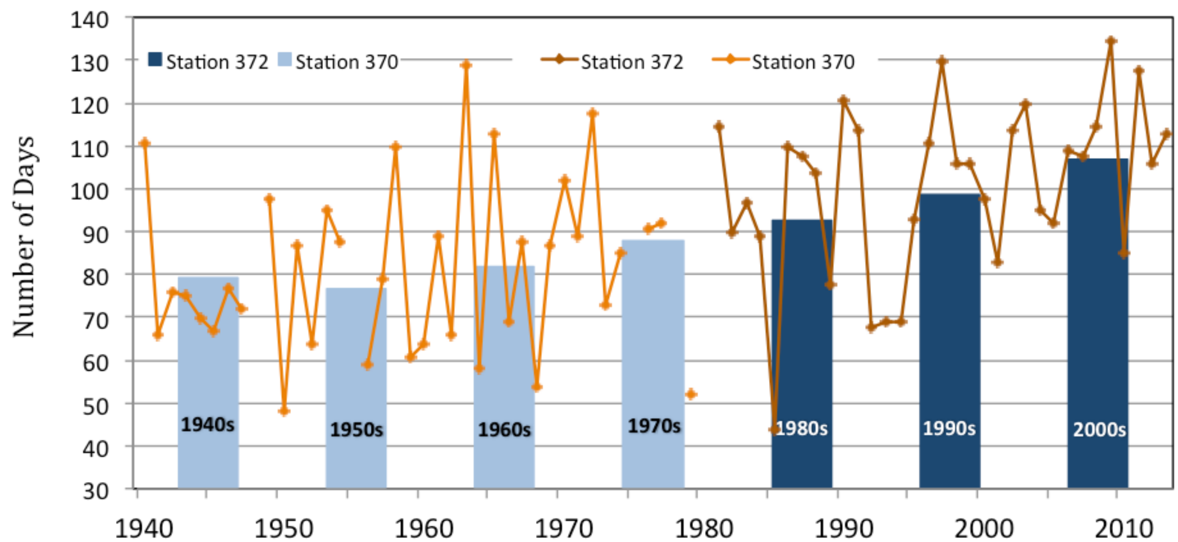

Figure 2.6 shows a rise in average consecutive frost-free days since the 1940's. The blue bars show decadal averages, and the orange line shows yearly frost free days. The location of Aspen's weather monitoring station changed between 1979 and 1980, shifting upward in elevation ~200 feet. Data source: NOAA-NCDC Aspen Stations 370 and 372.

Precipitation

Precipitation records in Aspen show high year-to-year variability, and the data set from the original Aspen station (Station 370, 1940-1969) differs in slope direction from the current data set (Station 372, 1981-present). From 1940-1969, average yearly precipitation increased by 2.9 inches. Since 1980, measurements at the new station have shown an 0.6 inch decrease in total yearly precipitation. The wide range of variation possible between years can be seen in the high precipitation of 1984 and the low precipitation of drought years such as 2002 and 2012. Annual average precipitation from 2004-2013 was 24.5 inches. Comparatively, the base period annual average rainfall from 1940-1969 was 18.8 inches. Again, the upward shift in precipitation after 1980 may be the result of the station change, but this is a speculation that cannot be confirmed. Unfortunately, the National Climatic Data Center (NCDC) does not provide overlapping data, and no statistical conclusions about the time period of the switch can be inferred (see Figure 2.7).

Similar to precipitation, total snowfall for a winter season showed a 9.6 inch increase over the period from 1940-1969, but over the time period of 1981-2013 there is a 9.9 inch decrease in winter-season snowfall (Figure 2.7). When the overall averages of two time periods are compared, however, 1981-2013 has, so far, been wetter than the average of the previous 30 years. Average winter-year snowfall from 1940 to 1969 was 134.8 inches. After the station change, from 1981-2013, the average rose to 170.2 inches (Figure 2.8,Table 2.1). The increase is in part driven by the fact that snowfall in the winter of 1983/1984 marked a new record high in Aspen's data set with 279 inches of snowfall in a single winter season. This contrasts with the winter of 1976/1977, which was the lowest snowfall since 1940 with only 61 inches. (This analysis of 1940-2013 precipitation and snowfall omits data from years with two or more months missing data). At 173.9 inches, average snowfall in Aspen in the last ten years (winter of 2004-spring 2013) is similar to the overall average snowfall of 170.2 inches during the entire 1981-2013 period.

Although data on precipitation patterns for Aspen do not illustrate notable directional trends, total annual precipitation or total winter-season snowfall are not the only factors critical in determining water availability in this region. Duration of snowpack, quantity of snow, dust on snow, and rain on snow events can all play an important role in water availability and timing throughout the summer.

Figure 2.7 Annual precipitation in Aspen

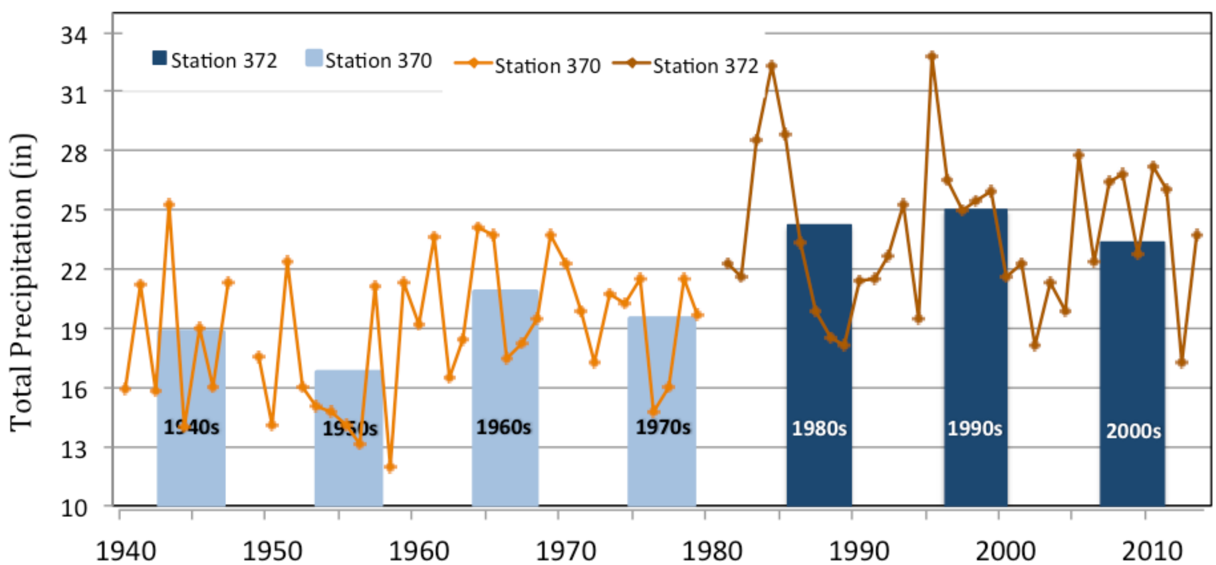

Figure 2.7 shows calendar-year annual precipitation in Aspen. Precipitation does not show a clear increase or decrease over time, although there is a shift in precipitation coincident with the station move in 1980. The location of Aspen's weather monitoring station changed in 1980, shifting upward in elevation ~200 feet. Data source: NOAA-NCDC Aspen Stations 370 and 372.

Streamflow

Trends in river flows, such as timing of peak runoff and discharge at peak, can also serve as indicators of changing precipitation and temperature patterns. However, the Roaring Fork Valley is a highly managed watershed with trans-basin and within basin diversions with flows determined by a variety of factors. Climate is just one of these factors, and all factors act in

Figure 2.8 Annual snowfall in Aspen

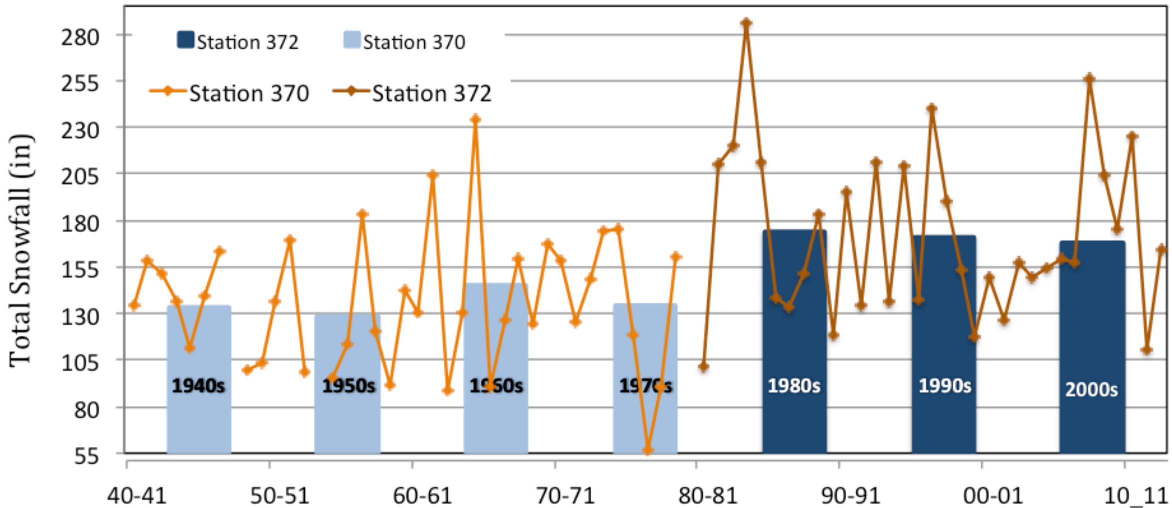

Figure 2.8 shows total winter-season snowfall for Aspen, which does not show a clear increase or decrease. A single year of snow was calculated as the total from the first snowfall in the autumn (August or later) of one year through the last snowfall in spring the following year (July or earlier). The location of Aspen's weather monitoring station changed in 1980, shifting upward in elevation ~200 feet. Data source: NOAA-NCDC Aspen Stations 370 and 372.

concert. In this section, an analysis of annual peak flows on the Roaring Fork River is provided, and these variables are discussed again in greater detail in the Chapter 4 section on water.

Data collected from the Glenwood Springs USGS station on the Roaring Fork River at the confluence with the Colorado River integrate many key upstream factors and can offer some insight into the timing and quantity of peak flow of the Roaring Fork River. Patterns at this station, however, are affected by natural variability, climate change, and water management. Additional factors include total precipitation, timing of precipitation, quantity of runoff from snowpack, upstream water use, water storage, in-basin diversions, and trans-mountain diversions to the Front Range (Figure 2.9).[23]

Additionally, a new area of research suggests the importance of the effect of dust on snow events in mountain hydrology. When dust settles onto snow, it decreases the snow's albedo, or reflectivity, meaning that that snow absorbs more of the sun's radiation, causing it to warm, and thus melt faster. A recent study about dust impacts on mountain snowpack in the Colorado River Basin found that existing perturbations from dust loading in the Colorado Rockies may be advancing peak runoff in the Colorado River by three weeks as measured by streamflow at

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[23] A more complete analysis of gage data and simulated data at different nodes in the Roaring Fork system or diversion and use impact on specific reaches of the Roaring Fork watershed are available in the State of the Roaring Fork Watershed Report 2008: http://www.roaringfork.org/sitepages/pid272.php.

Lee's Ferry, with the potential for an additional three week earlier onset during extreme dust events.[24]

While multiple natural variables contribute to determining peak flow, these variables also occur within the context of water management for human needs. The Roaring Fork River both serves as a source of municipal and agricultural water for local residents and is heavily diverted to the Front Range to meet trans-basin diversion agreements. Although little can be determined about climate-related shifts in river volume from USGS streamflow and peak discharge numbers alone, trends in streamflow describe the context in which the resiliency planning process occurs. Annual peak flow measurements for the GWS station show a decline in peak flow since the 1940s. Diversions are an important factor during the time period shown (Figure 2.9)

Figure 2.9 Annual Roaring Fork River peak flow at Glenwood Springs

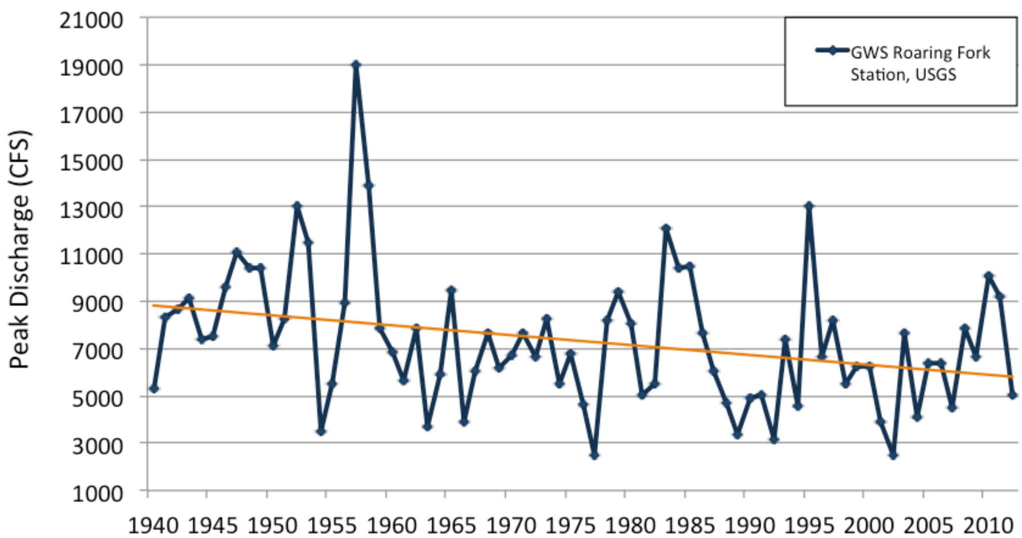


Figure 2.9 shows the date of peak discharge in CFS at the Glenwood Springs gage station since 1940. Peak for individual years and peak timing are impacted by a variety of factors such as precipitation, diversions, storage, evaporative losses, ground water recharge, and dust on snow. Source: USGS GWS Gauge Station.

[24] Deems, J. S., T.H. Painter, J.J. Barsugli, J. Belnap, and B Udall. 2013. Combined impacts of current and future dust deposition and regional warming on Colorado River Basin snow dynamics and hydrology. *Hydrology and Earth System Sciences 17* (11): 4401–4413. doi:10.5194/hess-17-4401-2013

Resources for access to observational data

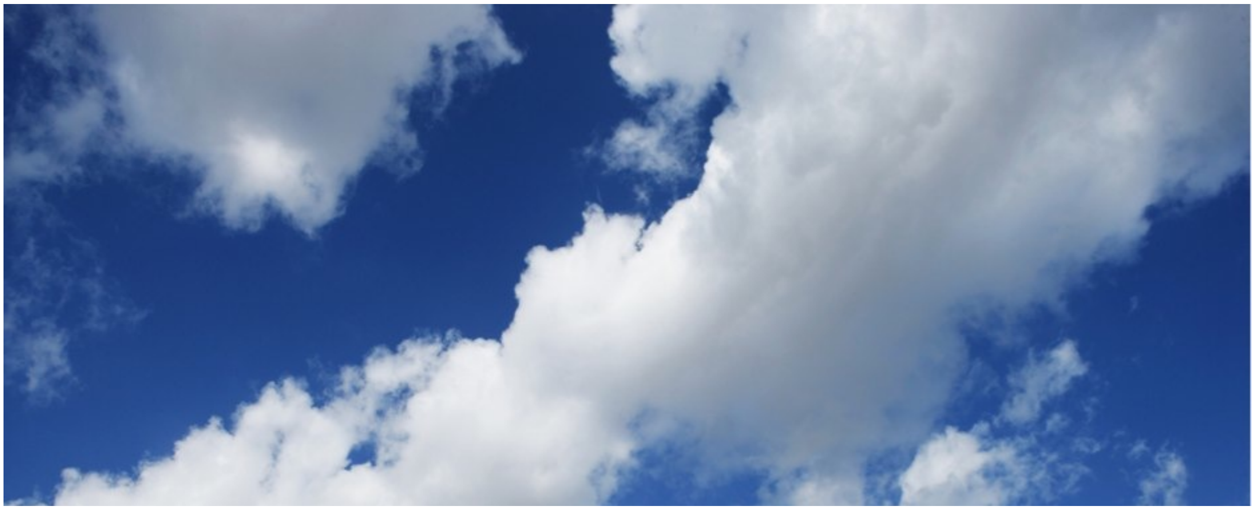
Ongoing monitoring of recent conditions in comparison to prior normal conditions can be one benchmark for assessing how much local conditions have or have not departed from normal conditions. For example, Table 2.2 provides a comparison of the most recent ten years, 2004-2013, to historical conditions during a 30-year base period, 1940-1969. Further information on past and current conditions can be found online through the US Geological Survey, the National Climatic Data Center (NOAA), and the National Resource Conservation Service (operators of SNOTEL monitoring network). Local information on river health can be obtained through the Roaring Fork Conservancy. In the near future the Integrated Roaring Fork Observation Network (iRON), a site to be developed by AGCI, will offer Valley-specific information about ecological parameters and collected data for climate parameters.

Table 2.2 Comparison of recent decade to 1940-1969 average

Observation	Base Period Average (1940-1969)	Last Decade Average (2004-2013)
Average, Minimum, and Maximum Temperatures	Ave: 41°F (5.0°C) Min: 25°F (-3.9°C) Max: 56°F (13.3°C)	Ave: 42°F (5.6°C) Min: 28°F (-2.2°C) Max: 56°F (13.3°C)
Frost Free Days	79 days	109 days
Total Annual Precipitation	18.8 inches	24.5 inches

Table 2.2 shows averages from a base period time, 1940-1969, in comparison with averages from the last decade, 2004-2013. The 1940-1969 data was gathered from NOAA Station Aspen 370, while the 1980-2013 data is from the Aspen Station's new location at 372, which is ~200 feet higher in elevation.

As discussed in Chapter 6, ongoing monitoring and analysis of environmental conditions, as well as monitoring of societal and ecological indicators, is a crucial component in creating strategies for successful adaptation to the local changes in climate.



CHAPTER 3: CLIMATE MODELING RESULTS

Introduction

Climate modeling for the region surrounding Aspen reinforces the finding from the 2006 Study that temperatures will increase. As in 2006, the magnitude of future warming is dependent on global greenhouse gas emissions, with higher emission scenarios producing greater projected changes within the models.

In terms of precipitation, new modeling analysis prepared for this study indicates slight increases in projections of future annual precipitation, with important seasonal variation. Higher emissions scenarios tend to equate to larger shifts in precipitation.

Changes in storm tracks, global scale patterns such as the jet stream, loss of Arctic sea-ice, and heat uptake and release by the oceans are all active areas of research. As the climate warms in response to the build-up of greenhouse gases, patterns of the past may no longer

Box 3.1 Key points from modeling results

- **Climate projections for the Aspen region significantly depend on future global greenhouse gas emissions.** Rise in global average temperature among low (RCP4.5) emissions is projected to be 5.3°F (3.0°C), versus 9.7°F (5.4°C) for high (RCP8.5) emissions, by 2100.
- **Modeling for the Aspen region projects increasing temperatures among all emissions scenarios over 21**
  Median results for the end of the century under a high emissions scenario suggest a nearly 10°F rise in temperature by 2100.
- **Precipitation projections for the Aspen region remain more uncertain relative to temperature but overall indicate a slight increase.** In many models, Colorado lies in a zone wherein projected drying in the Southwest transitions to projected wetter conditions in higher latitudes. As a result, models considering the Aspen region project a range that include increases and decreases in precipitation as well as little to no change.

Figure 3.1 Scenarios of global carbon emissions and temperature change

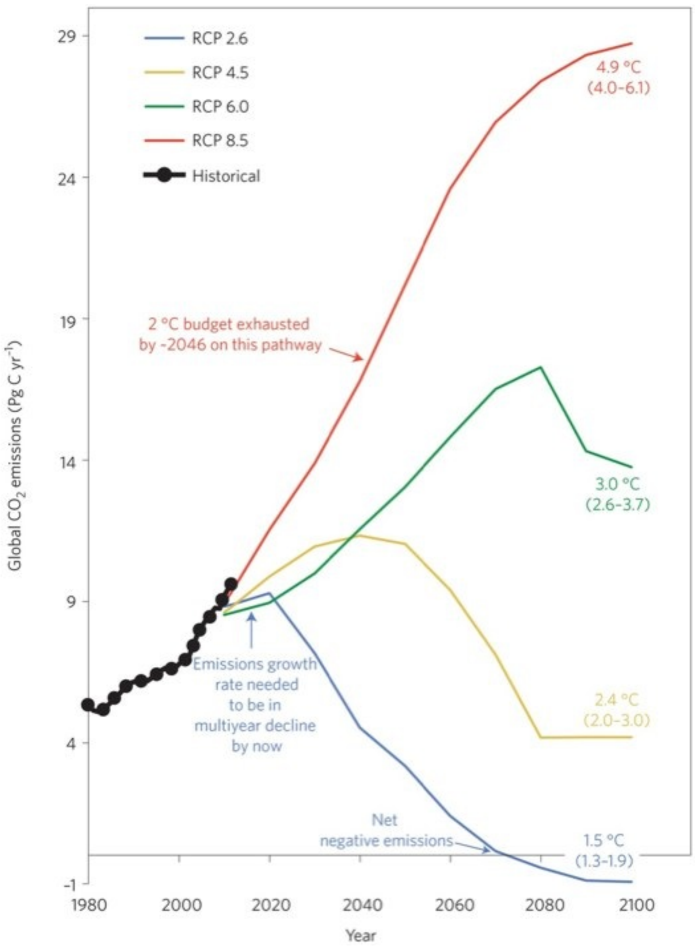


Figure 3.1 Four different scenarios of global CO_2 emissions (in trillion grams of carbon per year) for the 21st century. Based on the emissions scenarios utilized in the IPCC 5th Assessment Report (AR5), each scenario is labeled with an estimated global average temperature increase above pre-industrial levels, as produced by an ensemble of climate models. Observed emissions (black circles) continue to track the highest scenario (RCP8.5). Note that the lowest emission scenario (RCP2.6) requires negative emissions and that the projections in all scenarios do not include the effect of deforestation.
Figure source: Sanford et al. 2014.

provide an appropriate guide for projecting the future.[25] As a result, dynamic models of the Earth's climate become the primary tool available to characterize possible future climate conditions at global and regional scales.

A key set of inputs into modeling future climate is greenhouse gas emissions, which are based upon global energy and land use assumptions. The climate modeling community has adopted a new set of emissions scenarios known as Representative Concentration Pathways (RCPs), which are used in this report as well as the Fifth Assessment Report of the IPCC. These new scenarios are referred to as RCP2.6 (low), RCP4.5 (medium), RCP6.0 (medium-high), and RCP8.5 (high). The lowest scenario, RCP2.6, requires negative emissions by the later part of the century and is not considered in the analysis for this study.[26,27]

Generally speaking, climate models represent climate processes more accurately over larger spatial and longer temporal scales. Higher confidence is placed on projections of

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[25] Vano, Julie A., Bradley Udall, Daniel R. Cayan, Jonathan T. Overpeck, et al.. 2014. Understanding Uncertainties in Future Colorado River Streamflow. *Bulletin of the American Meteorological Society* 95 (1) (January): 59–78. doi:10.1175/BAMS-D-12-00228.1. http://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-12-00228.1.

[26] Modeling results in Chapter 3 primarily draw from a set of emissions scenarios called Representative Concentration Pathways (RCPs). The lowest RCP (2.6) indicates near term leveling off and reduction of greenhouse gas emissions over time. Other RCPs, in rising numerical order, present higher and higher assumptions of future emissions, with the highest (8.5) representing the current trend of the global economy.

[27] IPCC 2013

temperature than projections of precipitation. Near term, or decadal climate projections (i.e. 10-20 years) are in development and are not utilized in this study.[28] In the Southern Rockies, even the high resolution models cannot fully resolve the effects of mountain topography on regional climate systems.

Whereas the majority of results presented in 2006 were produced using modeling assessed in the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (2001), the results presented here stem from work assessed in the Fourth and Fifth Assessment reports (2007 and 2013-14, respectively).[29]

In this section, we update 2006 findings by utilizing subsequent generations of models not fully available in 2006 including:

- Emissions scenarios and global temperature projections
- Temperature and precipitation modeling results for the western Colorado region
- Surveys of other regional projections of temperature and precipitation

Emissions still matter

As in previous modeling analysis, climate projections assessed since 2006 continue to identify future greenhouse gas emissions, with CO_2 as the largest contributor, as the single most determinant factor in the amount of future increases in global average temperature change.[30] Moreover, since 2006, actual global emissions continue to follow the high emissions scenario. As Figure 3.1 illustrates, the range of global average temperature increase between the highest and lowest emission scenarios in 2100 is more than 6ºF (3.4ºC).
From this analysis, three points are relevant to Aspen:

- Efforts to mitigate future emissions of greenhouse gases can *dramatically* affect the overall magnitude of climate change experienced during the 21st century.
- The world is still on a high emissions trajectory with current and future alteration of climatic conditions that will have local repercussions.
- Multiple future pathways of climate change are possible and, as a result, planning for climate change should consider how to adjust to a range of potential outcomes.

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[28] See chapter 11 in IPCC 2013.

[29] IPCC 2001, 2007, 2013 [full citation provided in references]

[30] Moss, Richard H, Jae A. Edmonds, Kathy A. Hibbard, Martin R. Manning, et al.. 2010. The Next Generation of Scenarios for Climate Change Research and Assessment. *Nature* 463 (7282) (February 11): 747–56. doi: 10.1038/nature08823; Sanford, T., Frumhoff, P. C., Luers, A., & Gulledge, J. 2014. The climate policy narrative for a dangerously warming world. *Nature Climate Change*, *4* (3), 164–166. doi:10.1038/nclimate2148; IPCC, 2013.

As an update in this report, we present modeling analysis results from the most recent generation of GCM outputs for the western Colorado region. Utilizing the identical technique and study area implemented in an earlier generation of GCMs available in 2006 (CMIP3), these projections are based on the more recent CMIP5 and are intended to provide an updated glimpse of future temperature and precipitation possibilities for the Aspen region (see Appendix B, Figure B.1 for map of the region considered in this modeling analysis).[31,32]

A description of the methods utilized to derive these projections as well as additional data output from these projections is available in Appendix B. Table 3.1 provides a summary of the projected changes further elaborated in the sections below.

Table 3.1 Projected changes in temperature & precipitation for western Colorado

Change from historical period 1980-1999	Temperature change in °F (°C)	Precipitation change (%)
Medium Emissions Scenario (RCP4.5)		
2020-2039	+2.8 (1.6)	+1.4
2050-2069	+4.5 (2.5)	+2.4
2080-2099	+5.3 (3.0)	+3.1
Medium-High Emissions Scenario (RCP6.0)		
2020-2039	+2.3 (1.3)	+0.6
2050-2069	+4.3 (2.4)	+1.7
2080-2099	+6.6 (3.7)	+5.4
High Emissions Scenario (RCP8.5)		
2020-2039	+2.9 (1.6)	+1.9
2050-2069	+6.2 (3.5)	+3.0
2080-2099	+9.7 (5.4)	+4.2

Table 3.1. displays annual average changes in temperature and precipitation projected for three time periods and three emissions scenarios using an ensemble of Climate Model Diagnosis and Intercomparison Project (CMIP5) model output. Changes projected are relative to the historical period—1980-1999. There is more confidence in temperature projections than precipitation projections.
Data source: Model output analysis provided by C. Tebaldi, NCAR

[31] CMIP refers to the Coupled Model Intercomparison Project, an international effort that coordinates climate and Earth system modeling. For more info see: http://cmip-pcmdi.llnl.gov/

[32] A description of the results and methods utilized in 2006 are provided in section 2.5.4 (p 28-29) as well as in Appendix C (p.113-119) in AGCI, 2006.

Projected changes in temperature & precipitation for western Colorado

Results from this modeling work include projected mean temperature and precipitation as well as seasonal projections of temperature and precipitation presented as probability distributions. Results are presented for projection periods 2020-2039, 2050-2069, and 2080-2099 and represent values for an average year during each period. Full seasonal analysis as well as a comparison between the 2006 Study and the 2014 Study results is provided in Appendix B. A summary of projections is provided in Table 3.1.

Temperature results

Temperatures in the Aspen region are projected to increase among all scenarios considered and in all seasons. By 2030, there is no significant difference in the projection of temperature between scenarios, but by 2090 there is nearly a 4.5°F (2.5°C) change between median projections under the high (RCP8.5) and medium (RCP4.5) emissions scenarios. Under high emissions scenarios by the end of the century, temperatures are projected to increase more during summer and fall months than during winter and spring months. See Appendix B for more detail.

Precipitation results

There is much more confidence in regional projections for temperature than for precipitation, and precipitation is likely to remain uncertain due to challenges of climate projections in mountainous regions. Median projections of precipitation considered in most seasons under most scenarios indicate a slight increase in precipitation by 2030 and by 2090. However, a small percentage of model results project either significantly less or significantly more than historical amounts of precipitation. These results underline a significant point for resource management in the context of climate change: that uncertainty in projections calls for new planning methods that account for multiple possible future scenarios.[33] This approach is consistent with past planning approaches where both positive and negative extremes from natural variability (i.e. drought years and flood years) are incorporated in management strategies, but recognizes that climate state of the 20th century is in transition and no longer a reliable guide. See Appendix B for more detail.

Regional precipitation projections

Projections for precipitation change in the Southern Rockies, particularly in Colorado, are fraught with uncertainty, due in part to the challenge of resolving intricate micro-scale climate processes in the Rocky Mountains using the coarse resolution of global-scale climate models. Colorado has been identified to be on a "transition zone," situated between a section of the

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[33] Means, E. I., & Kaatz, L. 2010. Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning. Water Utility Climate Alliance.

Figure 3.2 Observed and projected precipitation in Colorado

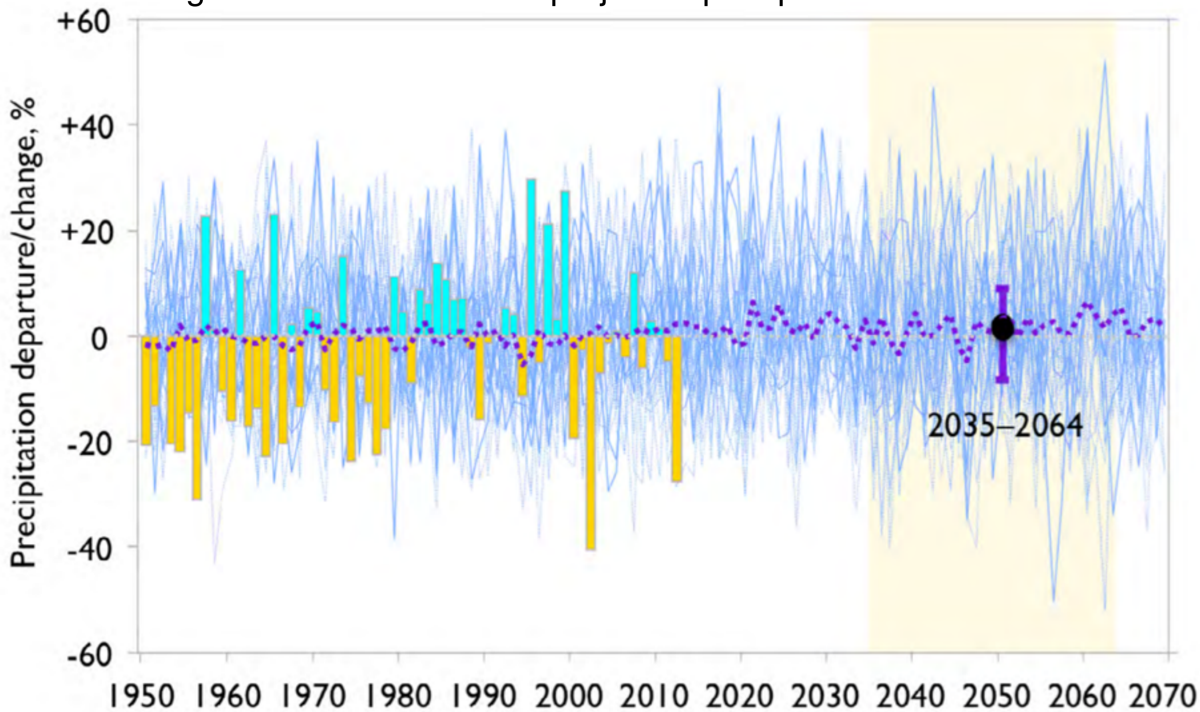

Figure 3.2 shows observed and projected annual precipitation changes in Colorado. Blue/orange bars represent observations 1950-2012. The dotted purple line represents the median of 37 model projections (individual model results shown in blue). The black dot represents the median result for the projection period 2035-2064 with the solid purple line representing the range of results from the 90th to the 10th percentile. All results are relative to 1971-2000 base period. Source: Colorado Water Conservation Board; Lukas et al. 2014.

North American continent that is anticipated to become wetter to the north and a section that is anticipated to become drier to the south throughout the course of the 21st century. Nevertheless, the central tendency of precipitation projections for the state show only slight change by the middle of the century under a medium emissions scenario, RCP4.5 (see Figure 3.2).

Model results therefore do not significantly agree upon precipitation projections for Colorado as a state and less so for specific regions of Colorado.[34] One of the steps in validating a new generation of models is adjusting for possible bias from observed conditions. This is an area of active research, but early indications suggest that CMIP5 modeling contains a wet bias in precipitation projections for our region, meaning that actual future conditions may actually be drier than current models suggest under any given scenario.[35] In addition, in many regions, models do not agree on whether a human-induced climate signal can be distinguished from

[34] Lukas et al. 2014

[35] Ibid.

Figure 3.3 Temperature projection comparisons for Colorado and Southwest region

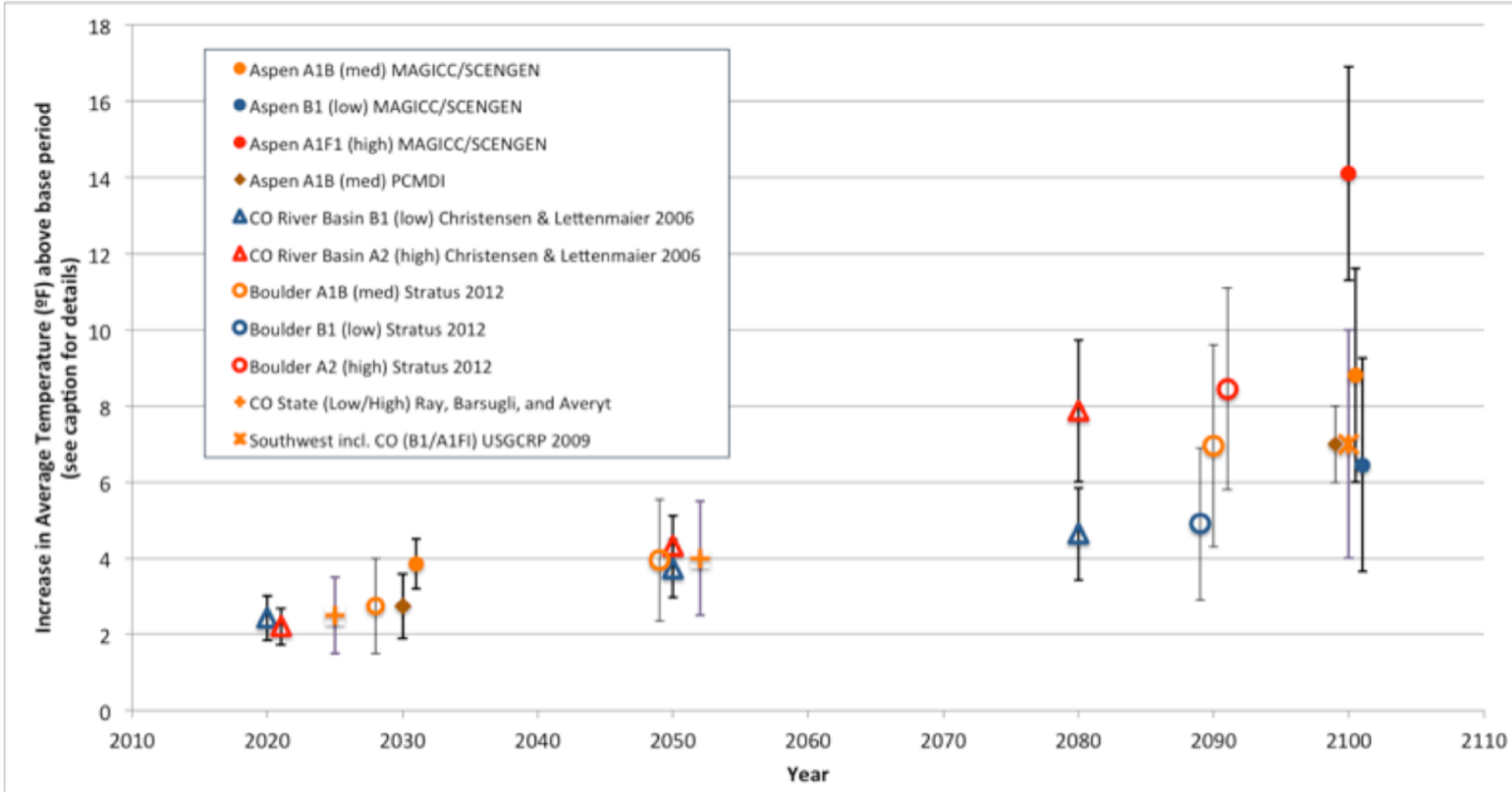

Figure 3.3 shows temperature projections from studies and assessments during the period 2006-2014 that were conducted for areas including or near by the Aspen area. Due to differences in geographic scope and methodology, the results provided here are intended for impressionistic comparison. Indicator colors of blue, orange, and red indicate various low, medium, and high emissions scenarios. The historical base period for Aspen MAGICC/SCENGEN results is 1976-2005; for Aspen PCMDI is 1980-1999; for Christensen & Lettenmaier (2006) is 1950-1999; for Ray, Barsugli, & Averyt is 1950-1999; for USGCRP 2009 is 1960-1979; for Stratus (2012) is 1950-1999. Projection ranges, as cited by the studies, are indicated by whisker plots. Black whiskers represent .25 and .75 range of model results with icon centered on .50 percentile; grey whiskers indicate .10 and .90 range of model results with icon centered on .50 percentile; purple whiskers represent high-end and low-end results among several scenarios with indicator centered on arithmetic mean

Figure 3.4 Precipitation projection comparisons for Colorado and Southwest region

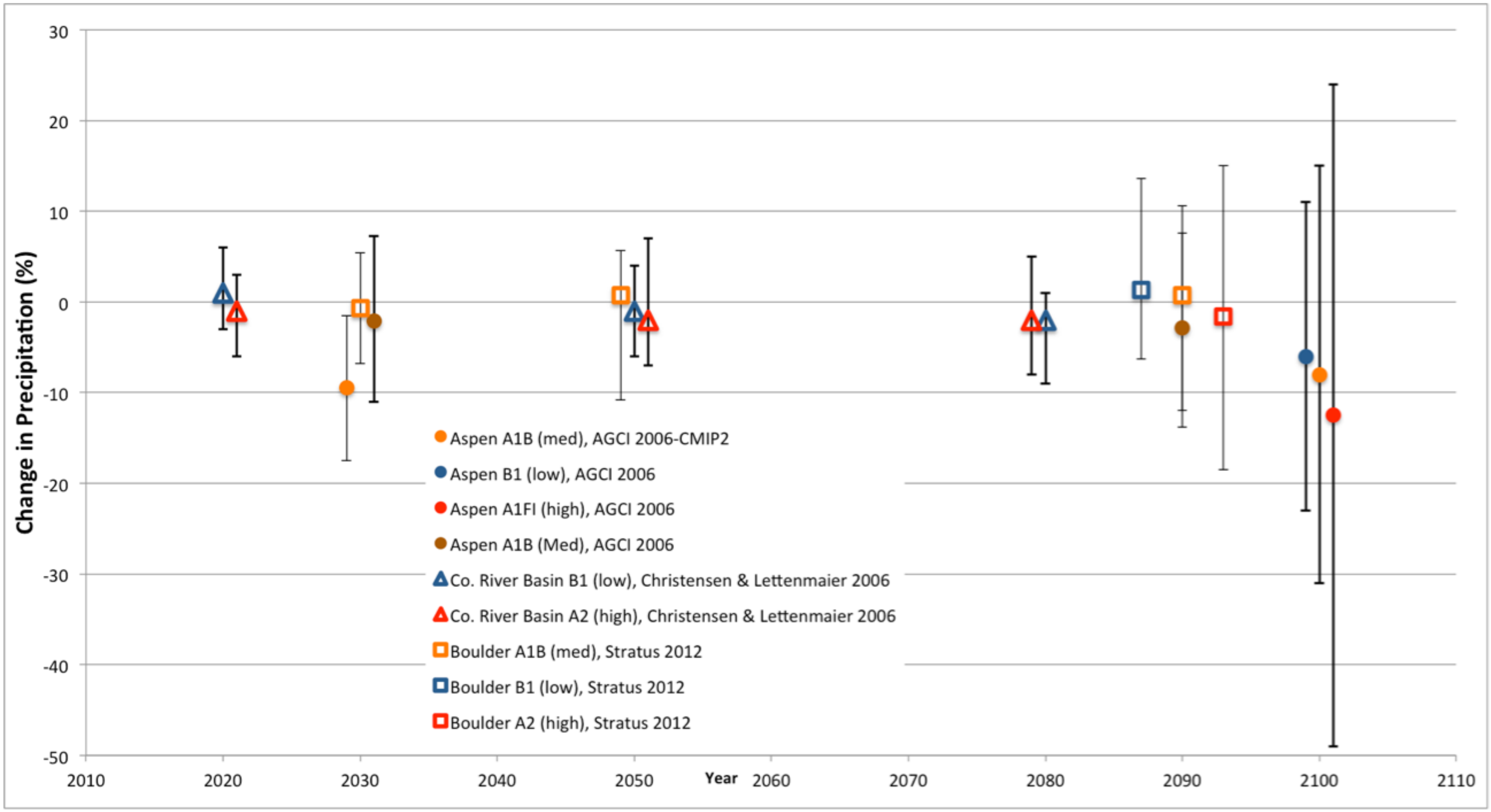

Figure 3.4. shows precipitation projections from studies and assessments during the period 2006-2014 that were conducted for areas including or near by the Aspen area. Due to differences in geographic scope and methodology, the results provided here are intended for impressionistic comparison. Indicator colors of blue, orange, and red indicate various low, medium, and high emissions scenarios. The historical base period for Aspen MAGICC/SCENGEN results is 1976-2005; for Aspen PCMDI is 1980-1999; for Christensen & Lettenmaier (2006) is 1950-1999; and for Stratus (2012) is 1950-1999. Cited projection ranges are indicated by whisker plots. Black whiskers represent .25 and .75 range of model results with icon centered on .50 percentile; grey whiskers indicate .10 and .90 range of model results with icon centered on .50 percentile. Results for 2020, 2050, 2090, and 2100 are shown slightly separated for clarity.

natural variability in precipitation, even by the end of the century.[36]

Regional temperature and precipitation projection comparisons

To present insights from modeling work conducted since 2006 for regions including or near to Aspen, a literature review was conducted that considered scientific publications and assessments containing temperature and precipitation projections. The projections contained within each of the publications examined were extracted along with relevant metadata such as study area, model selection process, emissions scenarios considered, base period, and uncertainty range. Results from this literature survey are plotted on Figures 3.3 and 3.4 along with selected results from the 2006 Study. Due to the diversity of methods utilized in different studies, these figures are intended to be impressionistic in order to highlight general areas of agreement or disagreement between recent results and those presented in the 2006 study.

Figure 3.3 indicates that among all the results in the literature surveyed, including results from the 2006 Study, increases in temperature are projected among all emissions scenarios. Toward the end of the century, the temperature increase projections for Aspen's region (2006) under middle emissions scenarios are comparable to the high emissions scenario results for Boulder, Colorado and the Colorado River Basin. This is consistent with expectations that higher elevation areas are anticipated to warm more relative to lower regions.

Figure 3.4 indicates that among nearly all the results in the literature surveyed, the midpoint or 50th percentile result for precipitation change is projected as a slight decrease. However, the range of results for each projection includes the possibility for minor increases in total annual precipitation, and some projections under low and medium emissions scenarios forecast slight increases in precipitation. These projections are consistent with the results from the 2006 Study that indicated decreases in precipitation for midrange estimates but included ranges of uncertainty that incorporated even more significant decreases in precipitation as well as increases. These results, however, differ from new modeling presented in the previous section in that, for those updated results, median projections indicate a slight increase in precipitation.

[36] Tebaldi, C., Arblaster, J. M., & Knutti, R. 2011. Mapping model agreement on future climate projections. *Geophysical Research Letters*, *38*(23). doi:10.1029/2011GL049863

CHAPTER 4: SECTORAL IMPACTS

Introduction

At scales from global to local, climate change is anticipated to bring about a wide range of impacts that affect many, if not all, of the sectors critical to the economic and environmental wellbeing of communities. In this report, we provide an overview of potential impacts to key sectors in the Aspen community:

- Recreation & Tourism
- Water
- Ecosystems
- Public Health & Safety
- Energy
- Built Environment & Infrastructure

These sectors were chosen in consultation with the City while setting the scope of this study. The scope was not able to include every sector, although other sectors such as agriculture are likely to be impacted by climate change as well. Many of the climate-related trends and events affecting different sectors are similar, and the impacts on sectors are interrelated. As a consequence, effective resiliency planning often involves addressing impacts to multiple sectors at once. In Aspen's situation, water is a critical resource to every sector examined in this report.

Impacts within sectors important to Aspen are interrelated. Effective planning will likely include an integrative approach, considering resiliency in multiple sectors at once.

As illustrated in Table 4.1, climate-related changes or events, ranging from incremental to transformational, will influence each of the sectors analyzed in this report in multiple ways. The more significant the increase in atmospheric carbon dioxide, the more significant the impacts that can be expected in a particular sector. As a result, societal response will likely occupy a spectrum from gradual, incremental adjustments to more substantial, transformational changes. Changes will likely involve technical, behavioral, and policy adjustments and will occur at individual as well as organizational (e.g., NGOs and private sector) and governmental levels. Discussion of response strategies—ideas for how to approach resiliency planning—are provided within each sectoral subchapter.

While this overview highlights many of the impacts expected for sectors in the Aspen community, much of the research available is not specifically focused on Aspen. Therefore, limited statements can be made about expected changes particular to Aspen. The report focuses on generalized impacts from research focusing on the Southern Rockies and North America to draw conclusions relevant to Aspen's resiliency planning.

Table 4.1 Summary of possible impacts by sector

	Weather & Climate Related Event or Trend	Examples of Possible Impacts					
		Ecology	Water	Recreation	Health & Safety	Energy	Built Environment
Incremental Change	Change in average annual temperature	Gradual uphill shifts in plant and animal species	Evaporative losses from river and soils; changes in quality, quantity, timing of river flows	Challenge meeting target ski area conditions; alterations to timing of rec. seasons	Increased vulnerability to heat stress for vulnerable populations (e.g. elderly); increase in potential for VBD	Changes in energy demand and supply patterns over time	Changes in HVAC requirements
	Increase in frost free days	Increase in growing season; potential for invasive species	Early drying of soil in summer; greater irrigation demand	Expansion of summer recreation; impaired snowmaking conditions	Lengthened, intensified allergy season; increased fire risk	Increase in demand for energy for cooling systems; seasonal shifts in energy requirements	Deployment of efficient irrigation systems; change in engineering standards
	Change to local hydrology	Expansion of dry climate species; altered river ecology	Temperature driven evaporative losses	Shortened winter season; timing mismatch for rafting	Increased fire danger; air pollution from fire	Altered hydroelectric supply pattern	High water and low water impacts to infrastructure
	Changes in extreme temps	Heat/drought stress to sensitive species	Increased evaporation, evapotranspiration	Reduced conditions for snowmaking	Increased potential for heat stress; lengthened, intensified allergy season	Increased energy demand for cooling systems such as AC	Greater deployment of AC; intolerable conditions within existing systems
	Drought	Iconic species at risk (e.g. Sudden Aspen Decline)	Restrictions on water use; further risk of over-allocation	'76/'02 like skiing conditions; summertime wilderness use restrictions	Regional impacts to agriculture, local food production	Decreased water availability for hydroelectric production	Less water available for municipal use
	Extreme Precipitation	Destruction of some habitats	High water flows; localized flooding;	Hazards to recreational users and infrastructure	Flooding, flash flooding, landslides	Interruptions to energy production and distribution systems	Flood damage to buildings, bridges, roads
Transformative Change	Severe fire	Dramatic alteration to landscape	Debris flows into river; water quality impacts	Damage to recreational infrastructure; degraded aesthetic quality	Personal endangerment; heightened air quality risk	Impairment and/or destruction of energy production and distribution	Destruction of infrastructure and structures

RECREATION & TOURISM

Changes to Aspen's winter-based tourism

In the 2006 Aspen Study, Snowmelt Runoff Model (SRM) and SNTHERM results projected deteriorating skiing conditions on Aspen Mountain over the course of the 21st century among high, medium, and low emissions scenarios. For the highest emissions scenario considered, an end to skiing in Aspen was projected by 2100. So far the world continues to follow this high emissions pathway.[37]

In 2006, modeling assessed by AGCI projected an end of skiing in Aspen by 2100 under high emissions scenario. World emissions still continue along this pathway.

Historical observations and projected future changes in the Aspen area reinforce findings from 2006. These observed and projected changes pose significant challenges to winter recreation, based on the sensitivity of natural snow abundance and quality to changes in temperature and precipitation.

A survey conducted by the National Resources Defense Council (NRDC) showed that snow conditions do influence statewide demand for skiing in Colorado. The NRDC study found an 8% variance in skier days between high and low snowfall years. Although this variance was less than in other states' surveys, in Colorado 8% translates to 1.86 million fewer skier visits during a low snowfall year as compared to high snowfall year.[38]

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[37] Sanford 2014; IPCC 2013.

[38] Burakowski, E. and M. Magnusson. 2012. Climate Impacts on the Winter Tourism Economy in the United States. *National Resources Defense Council*, (December).

For decades, ski areas have adapted to natural variability by altering their opening and closing dates and by developing and expanding snowmaking capacity.[39] Snowmaking in Aspen, in its existing form, enables resort managers to achieve target conditions in time for a Thanksgiving opening and to sustain conditions through a springtime closing date. In recent years the Aspen Skiing Company has moved to reduce operational constraints from energy and water associated with snowmaking.[40]

However, climate-related barriers to snowmaking remain beyond the control of ski resort managers. One fundamental challenge due to climate change is the likely reduction of cold temperatures required for adequate snow production.[41] A still unexplored component of a shift to increased snowmaking is consumer reaction to increased dependence on snowmaking.[42]

Additionally, observations suggest that precipitation coming as rain instead of snow during the skiing season will be increasingly common, as was discussed in the 2006 Study. Knowles, Dettinger, and Cayan conducted a study on trends in the fraction of winter (Nov-Mar) with precipitation falling as rain versus snow in the Western United States for 1949-2004. Of the 261 sites analyzed, 74% showed the water content from snow as a smaller fraction of total precipitation.[43] In addition to managed downhill terrain, these types of impacts may also affect the safety and desirability of other winter recreation activities like cross country skiing and back country skiing.

In Colorado, 1.86 million fewer skier visits occur during a low snowfall year as compared to high snowfall years.

As demonstrated in the 2006 Study using economic base analysis, winter recreation has been the magnet and economic engine for numerous related components of Aspen's culture and economy—from restaurants, outfitters, and professional services to sizable real estate transactions, home remodels, and home building. Some of the visitors in the winter may not ski but come for other reasons associated with the ski culture. All of these things considered, changing future winter climatic conditions in Aspen and relative winter conditions in other resort communities may affect, positively or negatively, the overall allure for visitors to Aspen

39 Bark, R. H., B.G., Colby and F. Dominguez. 2009. Snow days? Snowmaking adaptation and the future of low latitude, high elevation skiing in Arizona, USA. *Climatic Change* 102 (3-4): 467–491. doi:10.1007/s10584-009-9708-x

40 Interview with Rich Burkley, Aspen Skiing Company, January 17, 2014

41 UN World Tourism Organization, & UN Environmental Programme. 2008. Climate Change and Tourism: Responding to Global Challenges. Madrid, Spain. Retrieved from http://sdt.unwto.org/sites/all/files/docpdf/climate2008.pdf

42 Bark et al. 2009

43 Knowles, N., Dettinger, M., & Cayan, D. 2006. Trends in Snowfall versus Rainfall in the Western United States. *Journal of Climate*, 4545–4559. Retrieved from http://journals.ametsoc.org/doi/abs/10.1175/JCLI3850.1

Box 4.1 Recreation and tourism summary

Climate-related changes:
- Increasing wintertime temperatures
- Reduced fraction of precipitation falling as snow
- Increasing stream temperatures
- Alterations to timing and quantity of stream runoff

Future Potential Impacts
- Difficulty meeting target ski area conditions during existing season
- Reduction in suitable weather conditions for snowmaking
- Alterations to timing of ideal summer and winter recreation conditions
- Degraded aesthetic quality of environment; increasing hazards posed to visitors

Potential Responses
- Increased reliance on snowmaking
- Marketing and communication to attract visitors at non-traditional times
- Diversification of tourism in relation to economic base
- Extension of summer season events and activities
- Development of long term plans among providers of recreation and tourism services

Opportunities
- Expanded time period for summer season activities
- Reduction of shoulder season lull

Lingering Uncertainties
- Future trends in overall snowfall
- Adaptability and preferences of visitors
- Cascading effects of climate change on Aspen's economy

throughout the entire year. It is not possible to predict in this study how specific conditions may play out for local economy and future investment, but potential scenarios could be considered with the help of additional research and engagement with stakeholders. As pointed out in the 2006 study, because of Aspen's relatively high and cold ski mountain terrain relative to many other resorts, its skiing conditions may be superior to many other resorts as climate change progresses.

Changes to Aspen's summer-based tourism

Climate-dependent recreational activities during the summer include water-based activities, such as rafting and fishing, and activities in the forest, such as hiking and biking. Changing conditions within the forest may result in indirect impacts to activities such as hiking and mountain biking. This section addresses the more direct and significant potential impact on recreation from alterations to the hydrograph.

The 2006 Study presented runoff modeling results that projected substantial alteration in the timing of peak flows of the Roaring Fork River at Woody Creek. Subsequent to this, a statewide study by Clow analyzed data from 70 SNOTEL stations and dozens of gauge stations across the state. This research found that in the past 29 years there has been a 2-3 week timing shift in snowmelt and runoff. These types of changes, along with low flow years, may in the future cause the timing of rafting demand to go out of sync with ideal rafting conditions on the upper Colorado River.[44]

Climate change could also significantly alter recreational fishing, a summer tourist attraction in the Aspen area. Warming stream temperatures have the potential to impact success of trout and other cold water sport fish by altering timing of growth and development and changing availability of food supplies.[45] Along with impacts directly associated with warmer temperatures, aquatic habitat attributes such as dissolved oxygen and stream depth are affected by temperature and streamflow.[46] Simple climate-related snowmelt modeling of the upper Roaring Fork indicates a likelihood of reduced snowpack with earlier peak runoff and greater seasonal flow variability during the 21st century.[47]

As recent observations (see Figure 2.6 on frost-free days) and future projections (see Chapter 3) suggest, the length of Aspen's warm season is elongating. This presents an opportunity for expanded summertime recreational activities during what has typically been considered an "off season" or "shoulder season." However, expanded summertime recreation will present new challenges for water and land resource managers, who will have to plan for new demand and potential impacts from increased resource use.

Another component of climate-related change to summer tourism is the potential for wildfire risk to increase with drier conditions and higher temperatures. The risk of fire, as well as other extremes such as drought and flood, may affect both the logistical ability as well as the desire to engage in summertime activities before, during, and/or after these type of sudden events. In addition sudden changes such as fire and even more prolonged, gradual changes from drought can significantly affect the aesthetic character of the landscape, a notable attraction of the area for tourists.[48]

Response strategies

The response strategies undertaken by providers and users of recreational services will vary according to existing capacity to adapt, the magnitude of change anticipated or experienced, and the overall sensitivity to actual or projected changes. For instance, ski area operators are experienced with and have many existing options at their disposal to respond to climate and

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[44] Clow, D. W. 2010. Changes in the Timing of Snowmelt and Streamflow in Colorado: A Response to Recent Warming. *Journal of Climate* 23 (9): 2293–2306. doi:10.1175/2009JCLI2951.1

[45] Reiman, Bruce and Dan Isaak. 2010. Climate Change, Aquatic Ecosystems, and Fishes in the Rocky Mountain West: Implications and Alternatives for Management. General Technical Report for the U.S. Department of Agriculture and U.S. Forest Service November 2010.

[46] Ptacek et al. 2003.

[47] AGCI 2006; IPCC 2007.

[48] See Chapter 4 sections on Ecosystems and Public Health and Safety for more on fire risk.

weather-related changes. On the other hand, service providers such as lodging operators likely have fewer options to consider when contemplating significant operational changes on the basis of climate and weather patterns.

Responses may involve proactive or reactive actions in coordination with broader community planning guidance (e.g., Aspen Area Community Plan) or climate-specific policy actions undertaken independently. Collaborative planning—incorporating broad-based stakeholder involvement—may help to devise responses that address specific concerns, while flexibility in discussion and planning structure accommodates the evolving nature of available climate information and risks.

Scientific discussion of climate change impacts typically involves timescales between 30-100 years into the future. However, in our assessment of literature and stakeholder interviews, we found that planning within the recreation and tourism sector, particularly among private enterprise, occurs over much shorter, more near-term timescales.

For example, at the Aspen Skiing Company, long term planning consists of capital investment planning typically in 10-year increments for significant investments, such as ski lift development and snowmaking equipment.[49] Rafting and fishing guide companies typically respond to conditions at seasonal or day-to-day timescales. One constraint to long-term planning is that operational forecasts of climate or hydrologic conditions are typically unreliable beyond the current water year. While the skill of ski area operators to manage frequently changing forecasts and surprise shifts in weather is a valuable human resource for dealing with change, this embedded culture may lead to somewhat of a barrier when future changes depart from existing ranges of variability and require longer term planning and novel strategies.

Overcoming the barrier to thinking long-term may be facilitated by the support of governmental entities, such as the City of Aspen, that have mandates to consider and plan for potential risks to the community over more distant time scales. Scenario planning where specific futures are not predicted but multiple potential outcomes are considered is one approach.[50] An example of long range planning is the City of Aspen and Pitkin County's Aspen Area Community Plan that presents a vision and policies to support community development over a 10-year time span.[51]

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[49] Interview with Rich Burkley, Jan 17, 2014

[50] Peterson, G. D.,G.S. Cumming, and S.R. Carpenter. 2003. Scenario Planning : a Tool for Conservation in an Uncertain World, *Conservation Biology* 17 (2): 358–366.

[51] City of Aspen & Pitkin County. 2012. Aspen Area Community Plan. February 27, 2012. http://www.aspencommunityvision.com/media/uploads/FINAL_AACP_2272012_reduced.pdf

WATER

Water plays a critical role in each of the sectors discussed in this report: it determines ecological success, influences health and safety, drives production of energy, and impacts the economy in a myriad of ways. In Aspen and throughout the West, changes in water supply and demand are already active areas of discussion, research, and planning. Locally, studies such as the *State of the Roaring Fork Watershed Report* and resulting *Roaring Fork Watershed Plan* have already explored many of the significant issues and trends affecting local water availability and quality.[52] At a state level, Western Water Assessment (WWA) produced a 2014 report for the Colorado Water Conservation Board (CWCB) examining the impacts of climate change in Colorado with a focus on water.[53] The CWCB also facilitates roundtable discussions and is involved in the creation of a basin-wide implementation plan that will assess consumptive and non-consumptive water needs in relation to water supply across Colorado's nine basins.[54]

Water management, a perennial challenge in the West, is further complicated by the prospect of climate change.

The purpose of this section on water is not to reproduce earlier studies or to examine all the numerous and complicated water issues in depth. Rather, the purpose is to highlight potential impacts from climate change on water-dependent resources. This general survey of potential climate-related impacts to the water sector should be considered in the context of numerous ongoing water availability studies and water management planning activities—locally, statewide, and regionally. For example, the City of Aspen water department has commissioned a water

[52] Clarke, S., K. Crandall, J. Emerick, M. Fuller, et al.. 2008. State of the Roaring Fork Watershed Report. Ruedi Water and Power Authority and Roaring Fork Conservancy, November 2008.

[53] Lukas et al. 2014

[54] A draft and proposed framework for Colorado's Water Plan can be found at: http://coloradowaterplan.com.

availability study and drafted a water efficiency plan that are intended to explore the issues discussed in this chapter in further detail and specificity.

Due to the difficulty of scaling models to address topographic variability in the Colorado Rockies, projections for future precipitation in the Roaring Fork Valley continue to include multiple possibilities, ranging from little or no change to either significant decreases or even increases. Projections for the southwestern U.S. *as a region,* however, show greater agreement among models and indicate a general decrease in annual precipitation.[55] These projections suggest that the southwest area of the United States may become more arid as temperatures increase, snowpack decreases, and runoff dates become earlier. Because of the geographically connected nature of watersheds and existing water law and agreements, such as the Colorado River Compact, precipitation and water availability changes that take place regionally will have a considerable impact locally for water management in the Roaring Fork Valley.[56]

While future trends for quantity of precipitation in the state of Colorado remain uncertain, trends more confidently indicate that the *form* in which the precipitation will fall is likely to alter over time. A shift to an increased percentage of precipitation falling as rain rather than as snow is projected both locally and at a regional level, particularly at elevations below 8,200 feet. This is an alteration that, combined with higher temperatures and earlier snowmelt, has the potential to impact groundwater and surface water supplies.[57]

Pitkin County's population is expected to increase by more than 50% to 25,229 people by 2025.

Additionally, higher average temperatures affect water resources. Streamflow is often used as a proxy measurement for water availability, and research indicates that higher temperatures may directly correlate with lower streamflow. Hydrologic modeling for the gage station at Lee's Ferry in Arizona showed that for every 1.8°F (1.0ºC) increase in average temperature, streamflow in the Colorado River declines between 3-10%.[58]

Furthermore, any climate-related shifts in water availability that take place occur within the context of changing human demographics as well. Population growth locally and on the Front Range is anticipated to continue, increasing demand for water and the likelihood of potential water shortages by stretching an already limited resource. According to 2010 data from the state demographer's office for the state of Colorado, Pitkin County's population is expected to swell

55 Lukas et al. 2014.

56 Vano et al. 2014.

57 Ray, A., J. Barsugli, and K. Averyt. 2008. Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation. A Report for the Colorado Water Conservation Board. Western Water Assessment.

58 Vano et al. 2014.

from the 2010 population of 17,148 to increase by more than 50% to 25,229 people in 2025.[59] The population of Colorado as a whole is expected to grow significantly as well, reaching around 7.1 million residents in the next 16 years.[60]

Although Aspen sits at the top of the watershed, its water resources are unusual in that demand pulls water in two directions: downstream toward the southwestern states and eastward via diversions to the Front Range. Two of the five largest transmountain diversions in Colorado redirect water from from the Roaring Fork Valley.[61] Under conditions typical to the last few decades, spring streamflow of the Roaring Fork and Frying Pan Rivers were reduced by more than half due to diversions alone.[62] Diversions are essential for municipal uses and for agricultural production, so drying in the Front Range of Colorado and across the Southwest would doubly place pressure on local water availability from the standpoint of demand.

Impacts to snowpack and the water cycle

A 2014 report produced for the Colorado Water Conservation Board (CWCB) found that since the 1980s onset of snowmelt has shifted earlier in the year by 1-4 weeks and is projected to continue shifting to earlier in the year in the future as a response to warming temperatures.[63] The CWCB's previous 2008 report[64] found that between 2000 and 2004, the Colorado River experienced its lowest 5-year flow since records began in the early 1900s, and hydrologic studies project that low flows may continue as a result of declining runoff—as much as a 6-20% decrease from 20th century averages in the Colorado River Basin. The cited drivers for this decline are increased drought severity in the Western US and high temperatures exacerbated by decreases in soil moisture.[65]

On a local level, records from the USGS Glenwood Springs gage station show that from 1981 to 2012, peak flow showed a decline of 722 cubic feet per second (see Figure 2.9). Peak flow, the quantity of water in the river on the date of its highest flow of the year, is often considered to be indicative of of depth of snowpack for the preceding winter in snowpack dominated watersheds. Because the Roaring Fork is a heavily diverted river, the observed decline is more indicative of

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59 DeGroen, Cindy. 2012. Population Forecasts (Presentation). State Demography Office Annual Meeting, Colorado Department of Local Affairs, Nov.
60 Clarke et al. 2008.
61 More information available through the Roaring Fork Watershed at: www.roaringfork.org/sitepages/pid170.php
62 Clarke et al. 2008.
63 Lukas et al. 2014.
64 Ray, A., J. Barsugli, and K. Averyt. 2008. Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation. A Report for the Colorado Water Conservation Board. Western Water Assessment.
65 Lukas et al. 2014.

ongoing diversions to the Front Range than it is of local snowpack conditions. Local snow water equivalent (a proxy of snowpack) has not decreased sharply since 1981 (see Figure 4.1).

As discussed in Chapter 2, precipitation and snowfall within the Aspen area have been variable over the period of their observation from 1940-2013. Since 1981, both the data records for precipitation and snowfall have suggested slight decline, although both were increasing in the period before 1980 and the extraordinary winter of 1983/1984 skews the trend analysis (Figures 2.7 and 2.8). As temperatures continue to rise, though, duration of snowpack and percent of precipitation falling as snow rather than rain may decline. Depth of snowpack and duration of snow cover are linked closely to watershed functions, winter ecology, and water availability.

Particularly in snowpack-driven watersheds, early snowmelt or low snowpack during winter months can decrease soil moisture levels throughout the following summer, affecting plant growth and stress.[66]

In addition to the ecologic changes associated with changing water regimes, water availability forms a critical component of the structure of all other systems in the Valley. Human activities as diverse as production of energy or summer water sports are dependent upon sufficient flows.

Figure 4.1 Snow water equivalent on April 1 since 1981

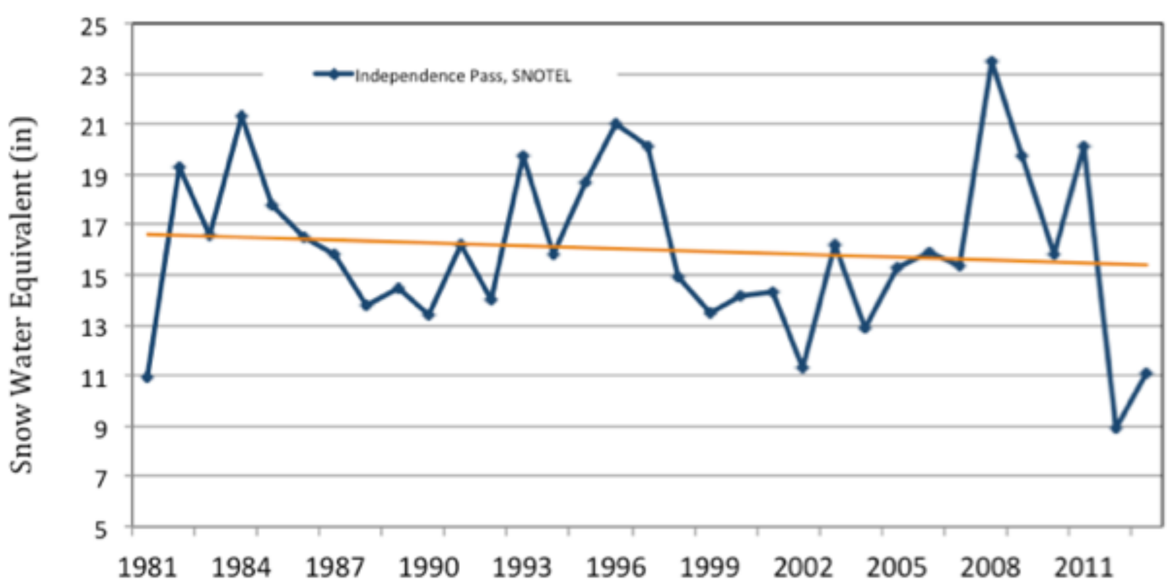

Figure 4.1 shows snow water equivalent (SWE) on April 1st in inches from 1981-2013. The blue line shows SWE for each year, and the orange line represents the overall trend of the data. The graph was created using NRCS data from the SNOTEL site on Independence Pass at 10,600ft.

66 Clow, David W. 2010. Changes in the Timing of Snowmelt and Streamflow in Colorado: A Response to Recent Warming. *J. Climate* 23: 2293–2306. doi: http://dx.doi.org/10.1175/2009JCLI2951.1

Winter recreation is tied closely to snowfall and duration of snowpack. Public health relies upon the assurance of water quality and availability, as do many aspects of our built environment and agriculture and local food production. Public uses, from municipal water supply and wastewater treatment plants to city parks and golf courses, rely upon water being available at critical times of the year.

Response strategies

Building climate resiliency in the water sector requires the consideration of many environmental, societal, legal, and ecological factors such as total annual precipitation, percent rain vs. snow, increases in temperature, soil moisture, population, and societal uses of and allocations for water.

Box 4.2 Water summary

Climate-related changes:
- Increased dry periods in the western U.S.
- Decrease in percent of precipitation falling as snow
- Changes to the timing and availability of water

Future Potential Impacts
- Greater pressure on existing water resources
- Changes to ecological regimes; decreased soil moisture, lower river flows
- Increased risk of fire
- Changes to timing and volume of peak flows
- Reduced hydroelectric generating potential
- Local population growth leading to increased municipal and recreational demand for water

Potential Responses
- Anticipatory planning and adaptation for multiple climate scenarios
- Increased water use efficiency
- Development of adaptive plans for ecological impacts
- Education and public outreach
- Stakeholder involvement in discussion and adaptive planning

Opportunities
- Renewed consideration of current water allocations, rights, and laws

Lingering Uncertainties
- Future trends in precipitation
- Seasonality of temperature changes in mountain climates under climate change
- Future population growth and water demand

Potential types of adaptation in the water sector include:

- Enhanced education and public outreach
- Local and regional research, monitoring, planning, and investment
- Ecological restoration and conservation

Activities of this sort are underway—and have been for many years— both locally and statewide, but they are now needing to integrate new shifting hydrologic conditions resulting from climate change. The Roaring Fork Watershed Action Plan recognizes the need and has considered climate change into actions proposed.[67] For Colorado, Governor Hickenlooper requested a State Water Plan be adopted that recognizes key issues such as population, the Colorado Compact, and climate change. All of these efforts are conducted in the context of existing policies and legal structures that could potentially evolve in the future.

[67] Clarke, S., M. Fuller, and R.A. Sullivan. 2012. Roaring Fork Watershed Plan. Retrieved from http://www.roaringfork.org/sitepages/pid175.php

ECOSYSTEMS

As of 2014, climate trends for the Roaring Fork Valley continue to follow the paths outlined in the 2006 report, with a growing number of frost free days and climbing average temperatures. Key ecological findings from the 2006 report remain pertinent.

Upward shifts in plant and animal distributions

Mountain habitats are comparable to islands in the sense that patches of equivalent habitat are isolated from one another. Both plant and animal species adapted to alpine ecosystems are vulnerable to climate change because they cannot move to higher elevation in response to warming temperatures.[68] Research published since 2006 continues to point to vulnerabilities in some alpine species native to the Aspen area, including the white-tailed ptarmigan, which may decline or even become locally extinct as a consequence of shifting climate conditions.[69,70]

Climate alterations may also cause species shifts or loss through alterations such as changes in form of annual precipitation (rain vs. snow), increases in temperature, or decreases in snowpack that may decrease winter soil temperatures critical to winter ecology. Such alterations can also impact the success of plant communities, causing shifts that cascade up the entire food

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[68] Olson, David, Michael O'Connell, Yi-Chin Fang, Jutta Burger, Richard Rayburn. 2009. Managing for Climate Change within Protected Area Landscapes. *Natural Areas Journal* 29 (4): 394-399.

[69] Imperio, S., R. Bionda, R. Viterbi, A. Provenzale. 2013. Climate Change and Human Disturbance Can Lead to Local Extinction of Alpine Rock Ptarmigan: New Insight from the Western Italian Alps. *PLoS ONE* 8 (11): e81598. doi:10.1371/journal.pone.0081598

[70] Beever, E. A., C. Ray, J.L. Wilkening, P.F. Brussard, and P.W. Mote. 2011. Contemporary climate change alters the pace and drivers of extinction. *Global Change Biology* 17: 2054–2070. doi: 10.1111/j.1365-2486.2010.02389.x

chain.[71,72] As conditions become sub-optimal for current plant communities, ecosystems in the Aspen area may transform to resemble communities currently found in lower, warmer conditions present in the mid-valley region and encroachments by invasive species may occur.

Potential for pest outbreaks in forest ecosystems

Among pest outbreaks currently of high concern for Aspen is invasion by the spruce beetle. Within the Roaring Fork Watershed, 20% of forest type is spruce-fir forest (as compared to only 9% lodge pole pine).[73] In 2012 and 2013, the Colorado Forest Insect and Disease Update cited spruce beetle as "the most damaging native forest insect pest" for the state, with spruce beetles infesting 398,000 acres of Colorado spruce forest in 2013.[74]

Climate change may increase tree susceptibility to disease or infestation as changes in disturbance regimes, temperature, and rainfall weaken resilience of native tree species. Furthermore, proliferation of pests like spruce beetles increases with rising average temperatures. Warmer spring and summer temperatures accelerate the life cycle of spruce beetles, allowing for more rapid development from pupa into adults and a rapid increase in population growth. Although still an active area of research, there is some early indication that winter temperatures that do not dip below -25°F (-32ºC) or -15°F (-26ºC) may allow greater over-winter survival of the larvae and adult beetles, respectively.[75]

Risk of increased forests fire size and frequency

In addition to susceptibility to insect invasion, forests in the Aspen area may also be vulnerable to alterations in fire regime as a consequence of climate change. Increased temperatures, decreased precipitation, earlier snowmelt, or increased presence of deadwood from insect outbreaks all raise risk of fire outbreak.

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71 Inouye, David W. 2008. Effects of Climate Change on Phenology, Frost Damage, and Floral Abundance of Montane Wildflowers. *Ecology* 89: 353-362. Available at: http://dx.doi.org/10.1890/06-2128.1

72 Parmesan, C. 2006. Ecological and Evolutionary Responses to Recent Climate Change. *Annual Review of Ecology, Evolution, and Systematics* 37 (1): 637–669. doi:10.1146/annurev.ecolsys.37.091305.110100

73 Meddens, A.J.H. and J. A. Hicke. 2013. Forest Condition and Forest Disturbance Metrics for the Roaring Fork Watershed, Colorado: A report for the Aspen Global Change Institute*. Department of Geography, University of Idaho.* July 26.

74 2013. Colorado Forest Insect and Disease Update: A Supplement to the 2013 Report on the Health of Colorado's Forests. Colorado State Forest Service. Available at http://csfs.colostate.edu/pdfs/2013FHR-InsectDiseaseUpdate.pdf

75 Jenkins, Michael J., Elizabeth G. Hebertson, and A.S. Munson. 2014. Spruce Beetle Biology, Ecology and Management in the Rocky Mountains: An Addendum to Spruce Beetle in the Rockies. *Forests* 5 (1): 21-71.

Figure 4.2 Incidence & extent of fires in the Roaring Fork Valley

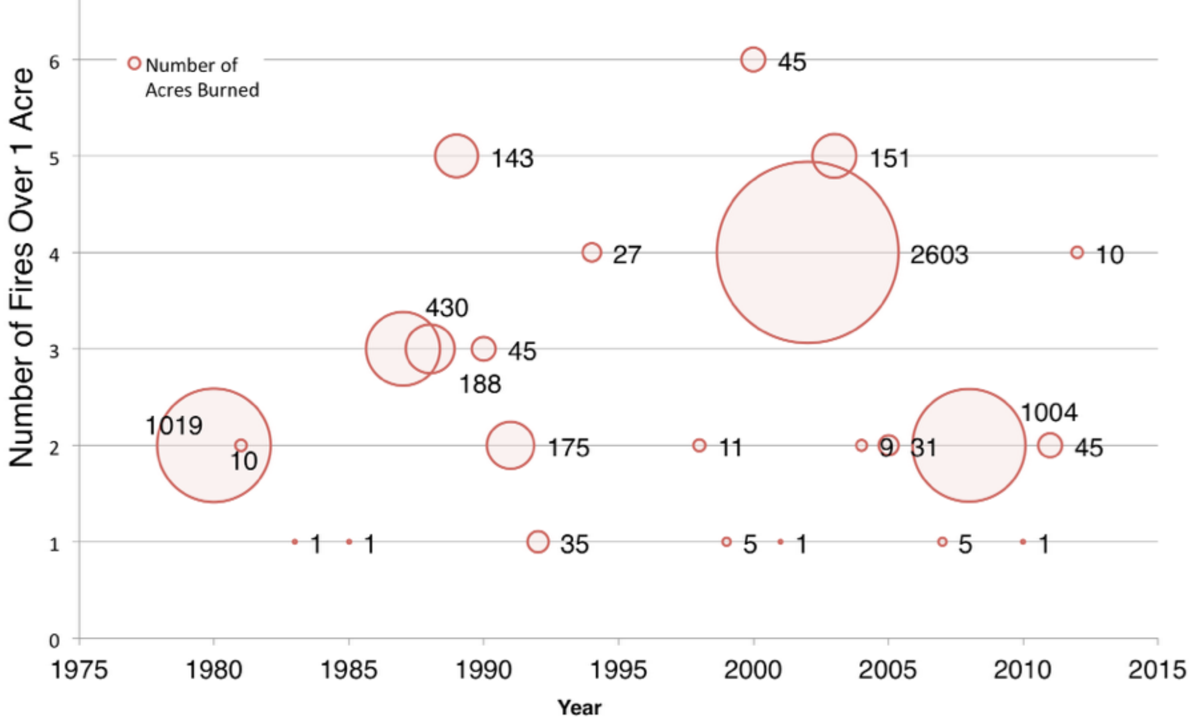

Figure 4.2 shows fires in the Roaring Fork Valley since 1975. The size of each circle represents the relative size of the fire, and the number beside each circle indicates the number of acres that were burned. Data source: White River National Forest.

In recent decades, a prior history of fire suppression and subsequent build-up of fuel, combined with climactic change and human activities, have contributed to an increase in size and severity of wildfires in the American West.[76]

In 2013, in the course of one month alone (June-July), more than 14 fires broke out in the state of Colorado. Furthermore, in part due to expanding exurban development, the fires of the last decade have been record-breaking in their destruction. The Fourmile Canyon Fire in 2010 destroyed 169 homes. In 2012 the High Park Fire destroyed 259 homes. Later that year the Waldo Canyon Fire burned 18,000 acres and consumed 346 homes. In 2013, 486 homes were lost in the Black Forest Fire.[77] Previous to 2000, the six most destructive fires in Colorado history destroyed fewer than 20 homes on average. For comparison, the largest fire near Aspen in the last 35+ years has been 2,603 acres, less than 1/6th the size of the Waldo Canyon Fire (see Figure 4.2).

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76 Marlon, Jennifer R., Patrick Batlein, Daniel G. Gavin, Colin J. Long, et al.. 2012. Long-term perspective on wildfires in the western USA. *PNAS* 109 (9): E535-E543. doi: 10.1073

77 Voiland, Adam. 2013. Nov. 8, 2013 Image of the Day. NASA Earth Observatory. Available at http://earthobservatory.nasa.gov/IOTD/view.php?id=82321

While high temperatures and drought conditions have contributed to the growth of these fires, a growing wildland-urban interface and the spread of development have also been cited as key factors driving the spike in property loss associated with Colorado's recent disasters.[78] The Aspen area includes many houses and developments situated in or near forested areas, and an outbreak of a wildfire in the Aspen area could have considerable economic, health and safety, and recreational impacts.

Unsuppressed, fires tend to occur on a cyclical basis, with differing return intervals for different forest types, but higher temperatures or dry conditions increase chances of fire outbreak and create potential for fires to be larger and more intense. Years with early snowmelt have been found to have five times as many fires as years with average snowmelt dates. Early snowmelt and runoff (and subsequent soil drying), combined with high temperatures, are projected to contribute to a 74-118% increase in wildfires in Canada within the next 100 years, with similar increases in the western United States.[79]

The 2006 City of Aspen report provides a more complete discussion of fire risk in relation to different fire suppression scenarios, available fuel, and climate change.

Response strategies

Options for adapting to shifts in the local ecological communities can be grouped into three management approaches:

- **Allowing changes to occur** without attempting to promote existing species over new species that may migrate into the ecosystem as warming occurs. Management would focus on passive study and monitoring of how these changes impact broader systems within the watershed.
- **Conservation**, where management supports specific species survival by working to preserve key habitats that are highly vulnerable to climate change. Additionally, corridors between comparable habitats might be created.[80]
- **Promoting specific species** via introduction of species to areas where projected future conditions will meet habitat needs. Species selected might be either species listed as currently threatened or those likely to become well adapted to future climate conditions.

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[78] Syphard, Alexandra D., Avi Bar Massada, Van Bustic, and Jon E. Keeley. 2013. Land Use Planning and Wildfire: Development Policies Influence Future Probability of Housing Loss. *PLOSONE* (Aug. 14). doi: 10.1371/journalpone.0071708

[79] Running, Steven W. 2006. Is Global Warming Causing More, Larger Wildfires? *Science* 313 (5789): 927-928. doi: 10.1126/science. 1130370

[80] Olson, David, Michael O'Connell, Yi-Chin Fang, Jutta Burger, and Richard Rayburn. 2009. Managing for Climate Change within Protected Area Landscapes. *Natural Areas Journal* 29 (4): 394-399.

Box 4.3 Ecosystems summary

Climate-related changes
- Increase in length of frost free period
- Alterations to the timing and type of precipitation
- Increasing annual and seasonal temperatures
- Alteration to snowpack quantity, areal coverage, timing of snowmelt onset and rate of melt

Future Potential Impacts
- Plant communities shift to higher elevations
- Local specialist species may diminish or disappear
- Increased likelihood of encroachment by invasive species
- Increased conditions for insect outbreaks
- Increase in factors contributing to wildfire incidence, intensity, and size
- Changes to local ecosystems types
- Local extinction of some alpine species
- Alterations to water quality or groundwater

Potential Responses
- Creation of migration corridors
- Reduction of human-related stressors on critical wildlife and habitat
- Identification and protection of priority species
- Collaborative, landscape scale forest management planning
- Public outreach and education about changes to ecosystems

Opportunities
- Potential re-establishment of natural fire ecology for some systems
- Collaborating with US Forest Service and Department of Parks and Wildlife on understanding changes to winter ecology

Lingering Uncertainties
- Future trends in precipitation
- Seasonality of temperature changes in mountain climates under climate change
- Forest response to potential management regimes
- Ecological resilience and ability to adapt to projected changes
- Ecosystem response to various potential restoration and management strategies

Either a species-specific or a broad, ecosystem-level approach may be taken when considering the best ways to preserve treasured natural assets. Regardless of strategy adopted, management plans and decision-making can be strengthened through a strong research base that identifies potential risks, trade-offs, and consequences of management options in relation to a variety of climate scenarios.[81] Adaptive forest management may likewise benefit from analysis of multiple potential scenarios and prioritization of goals or critical habitats. Millar et al. offer three ways to think of adaptive planning for forests:

- “Resistance” (plans that work to diminish or prevent climate impacts)
- “Resilience” (strategies to enhance an ecosystem’s ability to rebound after disturbance)
- “Response” (strategies that “facilitate transition of ecosystems from current to new conditions)[82]

For example, diversity in tree species offers natural resilience and resistance to host-specific pest outbreaks, but resistance can also be encouraged by management. Studies on outbreaks of pine beetles in the Canadian Rockies suggest that impacts of pests may be further mitigated by identification and targeted harvesting of high risk stands of trees and by management plans for control, salvage, and prevention of beetle outbreaks.[83]

Community outreach can also provide an important form of risk reduction. The Colorado Wildfire Risk Assessment Portal provides mapping and information about high fire risk areas, and the State of Colorado, among others, encourages development of community wildfire protection plans that include forest management plans and strategies for coping with new and existing development within forest areas. These responses includes: revising building codes, providing public education about defensible space, and developing plans for evacuation, many of which are already being implemented by the Aspen Fire Protection District.[84]

As humans increasingly live in and near forested areas, ecological plans will need to continue to overlap with social and structural planning and take into consideration desired human interactions, physical structures involved in encroachment, and associated laws and regulations. It may be particularly important locally that adaptive strategies consider ecological objectives within the context of other sectors. Examples for an integrative approach exist, as is demonstrated by action plans such as the *Hunter Creek-Smuggler Mountain Cooperative Plan*, which draws together a variety of stakeholders and identifies goals that range from biological to educational to economic in nature.

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[81] Turner, B.L., Roger E. Kasperson, Pamela A, Matson, James .J McCarthy, et al.. 2003. A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the United States of America.*

[82] Millar, C.I., N.L. Stephenson, and S.L. Stephens. 2007. Climate change and forests of the future: managing in the face of uncertainty. *Ecological Applications* 17 (8): 2145-2151.

[83] Schneider, Richard R.," Maria Cecilia Latham, Brad Stelfox, Dan Farr, and Stan Boutin. 2010. Effects of a Severe Mountain Pine Beetle Epidemic in Western Alberta, Canada under Two Forest Management Scenarios. *International Journal of Forestry Research* 2010. http://dx.doi.org/10.1155/2010/417595

[84] Wildfire Mitigation Webpage. Colorado State Forest Service, Colorado State University. Last updated 2013. http://csfs.colostate.edu/pages/wildfire.html

PUBLIC HEALTH & SAFETY

The 2006 Study did not provide a direct, in-depth discussion of the impacts of climate change to public health and safety, but general assertions made, such as the danger of wildfires to human health, still hold true. This 2014 report provides a preliminary assessment of potential impacts to human health and safety in the Aspen area as a result of climate change, though more detailed assessment based on site specific conditions and vulnerabilities is still needed.

Aspen's elevation and geographic location will likely serve as an important source of protection against some anticipated health impacts associated with climate change. Aspen is not immune to all potential risks, however. Some risks, such as wildfires, landslides, or deterioration of air quality, may have direct impacts on the health and safety of visitors and residents of Aspen. Other threats may be more indirect, such as increased anxiety about the state of the environment or altered mobility or economic stability of potential visitors to Aspen[85].

Visitors and locals alike would both be at risk in the case of catastrophic events, such as landslides or fires. While fires are an important natural cycle for ecosystems, they also pose serious threats to human health: loss of property and risk of direct physical harm and increase potential for related floods or landslides. With a large proportion of Aspen's population living and recreating in or near forested areas, potential health and safety consequences for Aspen from wildfires are considerable. In the western United States, the active wildfire season has increased by 78 days over the last century, and the odds of increasingly large or intense wildfires are anticipated to rise in the future.[86]

[85] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds. 2014. Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program: 841. doi: 10.7930/J0Z31WJ2.

[86] Running, Steven W. 2006. Is Global Warming Causing More, Larger Wildfires? *Science* 313 (5789): 927-928. doi:10.1126/science.1130370

Decreased air quality

Recent findings suggest that in addition to increased fire risk, the warmer temperatures associated with climate change may also have impacts on air quality. The early onset and greater duration of the growing season may increase the length of the allergy season, while CO_2 fertilization may increase pollen and spore production, worsening allergies for those with hay fever.[87]

Changes in temperature and precipitation regimes could have a significant impact on the spread of disease, even for high altitude locations.

Additionally, hot days often correlate with higher levels of ground-level ozone, so an increasing number of warm days could mean more frequent days with ozone levels above those considered healthy. Ozone is an oxidant and at high concentrations reacts with human tissue. High levels of ozone can irritate lung tissue, aggravate pre-existing respiratory conditions, and may contribute to increased likelihood of respiratory infections.[88]

Aspen's recent ozone levels (2013) have been below the EPA standard of 75 parts per billion, but high temperatures correlate with higher levels of ground-level ozone, so as temperatures rise, ozone levels throughout the summer months may also increase. [89]

Fine airborne particulate matter can also pose respiratory risks. Impacts of climate change on aerosols and particulate matter are still not fully understood, but increased incidence of fires would increase both. Further, changes in wind or weather patterns could change global distribution of pollution from transportation and industry as well as wind borne mineral dust from mining, fossil fuel extraction and recreation particularly from upwind desert areas to the west — all important source of particulates. Particulate pollution from combustion is released by high-temperature industrial processes, wildfires, gasoline and diesel engines, and during the production of fossil-based power.[90] Although the City of Aspen Electric system is on its way to

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87 Frumkin, Howard, Jeremy Hess, George Luber, Josephine Malilay, and Michael McGeehin. 2008. Climate Change: The Public Health Response. *American Journal of Public Health* 98 (3): 435-445. doi: 10.2105/AJPH.2007.119362

88 Climate Impacts on Human Health. Human Health Web Page. Last updated Sept. 2013. Environmental Protection Agency. Available at http://www.epa.gov/climatechange/impacts-adaptation/health.html

89 Aspen/Pitkin County Website. Data available at: http://www.aspenpitkin.com/Departments/Environmental-Health/Air-Quality-Outdoors/Ozone/Historical-Ozone-Levels/

90 Climate Impacts on Human Health 2013

achieving 100 percent of its electricity from renewables, pollution from far away sources and, locally, its busy streets will continue to affect Aspen air quality.[91]

Figure 4.3 Projected probability of presence of West Nile Virus

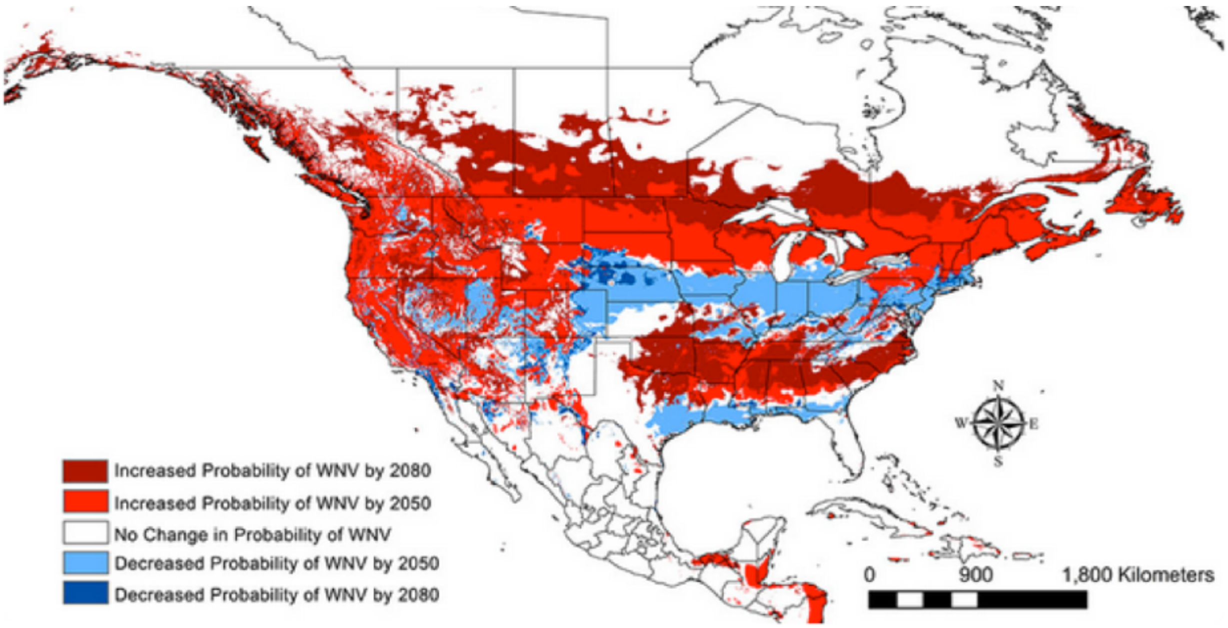

Figure 4.3 Probability of presence of West Nile virus (WNV) projected for the years 2050 and 2080 under the A1B middle emissions climate scenario. Areas in red indicate increased probability of WNV presence by at least 10% compared to current incidence. Areas in blue represent decreased predicted prevalence. Source: Harrigan et al. 2014.

Vector borne disease

As temperatures shift across the United States, so too will the range of animal species that are vectors for disease. As temperature and moisture regimes change, so too might the prevalence of carrier species, such as the birds and insects spreading vector borne diseases such as West Nile Virus (WNV).

The Center for Disease Control reports that there were 318 cases of WNV and 7 WNV-related deaths reported for Colorado in 2013.[92] A recent study by Harrigan and colleagues found a strong correlation between prevalence of West Nile Virus and higher temperature/lower

[91] Frumkin, Howard, Jeremy Hess, George Luber, Josephine Malilay, and Michael McGeehin. 2008. Climate Change: The Public Health Response. *American Journal of Public Health*. 98(3), 435-445. doi: 10.2105/AJPH.2007.119362

[92] Data available at: http://www.cdc.gov/westnile/statsMaps/preliminaryMapsData/histatedate.html

precipitation regimes.[93] As a result, climate variables can be used to project the probability of the presence of West Nile Virus (WNV), where higher maximum temperatures in the warmest month lead to higher probability of virus presence. Seasonal drying and lower annual precipitation were also associated with higher likelihood of outbreaks over the next 50-80 years. Harrigan et al also found that the geographic distribution of WNV was expected to shift northward and up in altitude with climate change, increasing probability of WNV by 2050 for the Rocky Mountain Region of Colorado, including high altitude locations (see Figure 4.3).[66]

The shift to warmer temperatures may also lead to an upward movement in the distribution of invasive mosquito species, including those typically associated with tropical habitats and tropical disease. Changes in land use, socio-economic conditions, human behavior, population density, and water use all may additionally play a role in prevalence and spread of transmission of vector borne diseases.[94] The presence of a disease such as WNV in the Aspen area could have significant negative impact on local bird populations and could pose a direct threat to human health.

Other potential threats to public health and safety include: mental health concerns, changes in food and water supply stability, and increased pressure on resources as a consequence of population increase. For example, climate change may impact mental health in the form of anxiety over associated environmental degradation or stress in relation to a climate driven disaster, such as a wildfire.[95] Additionally, both local and non-local food production may shift in relation to changes in climate patterns, water availability, and disruptions to global food markets.

Response strategies

Outreach, development of appropriate codes, increasing response capacity, identification of high risk locations, and structural changes are all potential strategies for adaptively managing climate-related risks to public health and safety. Building codes and conscientious development planning are key to helping prevent disasters such as fires or flooding and can assist in avoiding development of mosquito-prone areas.

Distribution of information can also help to ameliorate the health risks associated with climate change. Public education and outreach, particularly for tourists, can help to prevent illnesses

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[93] Harrigan, Ryan J., Henri A. Thomassen, Wolfgang Buermann, and Thomas B. Smith. 2014. A continental risk assessment of West Nile virus under climate change. *Global Change Biology*. John Wiley and Sons, Ltd. doi: 10.1111/gcb.12534

[94] Harrigan, Ryan J., Henri A. Thomassen, Wolfgang Buermann, and Thomas B. Smith. 2014. A continental risk assessment of West Nile virus under climate change. *Global Change Biology*. John Wiley and Sons, Ltd. doi: 10.1111/gcb.12534

[95] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds. 2014. Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program: 841. doi: 10.7930/J0Z31WJ2.

such as heat stress. Education can also play a role in disaster readiness. It can help to build compliance with laws and regulations and can encourage preparedness at a family level. For example, the Center for Disease Control promotes creation of escape plans and disaster kits in every home.[96]

Finally, promoting enhanced response capacity can improve community ability to meet a variety of as-of-yet uncertain health concerns. For example, health care providers may evaluate the

Box 4.4 Health and safety summary

Climate-related Changes
- Increased frequency of extreme high temperatures
- Increased risk of extreme events (e.g. drought, fire, flood, landslide)
- Increased presence of particulate matter and tropospheric ozone
- Changing ranges of disease-carrying species
- Changing climate conditions affecting food supply

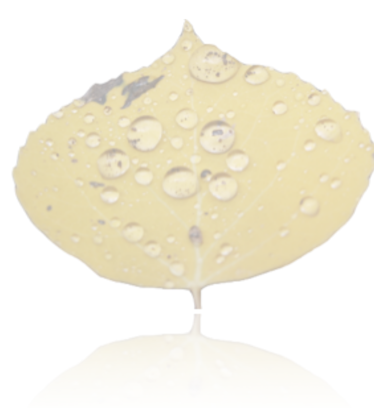
Future Potential Impacts
- Environmental stress-related mental illnesses
- Increased respiratory illnesses as a result of air quality impairment
- Increased incidence of vector borne diseases
- Loss of property or injury related to disaster events
- Lengthened and intensified allergy season

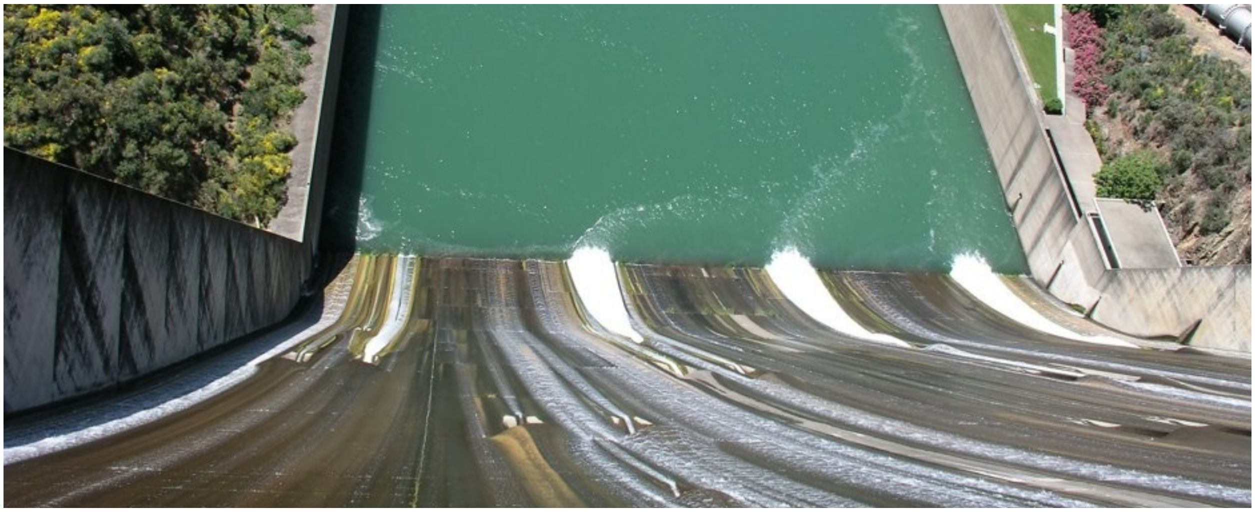
Potential Responses
- Assessment of high risk populations
- Address pre-existing local health concerns
- Prioritize potential threats to public health and safety in relation to existing capacities
- Assess and improve building codes and regulations in relation to changing hazards
- Public education and outreach
- Assess and improve early warning systems

Lingering Uncertainties
- Exposure of Aspen to vector borne diseases and other climate-related health risks
- Management impacts on wildfires
- Public response to changes
- Alteration of prevailing wind patterns
- Alteration of air quality from regional fossil energy extraction and production

[96] CDC's Building Resilience Against Climate Effects (BRACE) Framework. Climate and Health Program Webpage. Last updated 2012. Centers for Disease Control and Prevention. Available at http://www.cdc.gov/climateandhealth

vulnerability of local populations to respiratory illnesses or illnesses such as WNV and create plans accordingly. Outreach and education may also promote health and safety by improving compliance with regulations and creating a sense of community involvement, leading to empowerment and diminishing stress and uncertainty.





ENERGY

Energy use is tightly coupled with the climate challenge, both in terms of mitigation and adaptation. Emissions of greenhouse gasses from fossil fuels are the single largest contributor to anthropogenic climate change, and the impacts of climate change on the energy sector are anticipated to significantly affect the supply of and demand for energy at global and local scales. Options for reducing the carbon intensity of energy include increased utilization of renewables, which rely on variable resources such as sunshine, wind, or water.

The impacts of climate change on energy were not explicitly considered within the scope of the 2006 Study, but much of the climate and hydrological analysis from that study is pertinent to the assessment of impacts to Aspen's future energy supply and demand.[97] Factors such as changing normal and extreme temperatures, changing precipitation, and alterations to the timing and magnitude of stream flow carry ramifications for the resiliency of Aspen's energy supply. These factors may also influence ability to meet desired reductions in greenhouse gases as stated in the Climate Action Plan.[98]

Electricity supply implications

Renewable, low carbon energy sources rely heavily upon fluctuating natural resources such as moving water, wind, or solar radiation. As a result, renewable energy is in general more affected by change in weather or climate than fossil-based resources.[99] Aspen's energy supply is

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[97] See chapters 2 & 6, AGCI 2006.

[98] City of Aspen Canary Initiative. 2007. Climate Action Plan. City of Aspen. Available at http://www.aspenpitkin.com/Portals/0/docs/City/GreenInitiatives/Canary/CAP-final%20without%20dates.pdf

[99] Bureau of Reclamation. 2013. Literature Synthesis on Climate Change Implications for Water and Environmental Resources. Technical Memorandum 86-68210-2013-06. Denver, CO. Available at http://www.usbr.gov/climate/docs/ClimateChangeLiteratureSynthesis3.pdf

particularly exposed to potential changes in climate and hydrology because a significant portion of the City of Aspen's electricity supply[100] comes from snowpack-dependent river flows and reservoir storage that generate power through hydroelectric facilities, such as Ruedi Reservoir (see Figure 4.4).[101] In general, climate-related issues that concern hydropower generation include water quantity and quality, temperature-related stresses, and operational impacts due to extreme weather.[102] Another interesting factor linking Aspen's energy to global trends and climate change mitigation is the emergence of electric vehicles and the potential to shift away from gasoline to electric vehicles. This may transfer a greater proportion of Aspen's energy consumption to electricity in the coming decades.

Figure 4.4 City of Aspen utility electricity sources (2013)

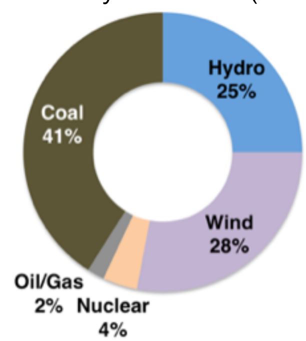

Figure 4.4 provides a snapshot of electricity sources for the City of Aspen Electric system in 2013. The composition of energy sources vary from year to year based on climate conditions and purchasing agreements. For instance, the portion of City of Aspen electric supply from hydro for 2014 is expected to be 37%, as compared to the 25% shown above. Source: City of Aspen.

At Ruedi Reservoir, the reservoir level, which is significantly affected by winter snowpack, is a key factor in energy production, along with other management concerns such as water rights, upstream diversions on the Frying Pan, recreational needs for the reservoir, water temperature for the Frying Pan fish ecology below the dam, and flood management. Figure 4.5 characterizes the relationship between winter snowpack measured at the Kiln SNOTEL station on April 1st and the annual electricity production generated by Ruedi. Although numerous variables play a role in water management and electricity production at Ruedi, there is a clear relationship between local snowpack and electricity production. This vulnerability is addressed to some extent by the existing diversity—both in location and type—of Aspen's electric supply mix and the ability to acquire sources outside the Roaring Fork Valley, but the correlation between snowpack and energy production highlights the potential for extreme conditions such as drought to alter renewable energy production on a year-to-year basis.

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[100] This considers only electricity supply provided by the City of Aspen operated electric utility and not the portion of electricity supplied to Aspen by Holy Cross Energy.

[101] City of Aspen-100% Renewable Power by 2015. Go 100% Renewable Energy Web Page. Renewables Policy 100 Institute. Available at http://www.go100percent.org.

[102] Bull, S.R., D.E. Bilello, J., Ekmann, M.J. Sale, and D.K. Schmalzer. 2007. Effects of climate change on energy production and distribution in the U.S. *Effects of Climate Change on Energy Production and Use in the U.S.: A report by the U.S. Climate Change Science Program and the subcommittee on Global Change Research.* Washington, D.C.

Over the long term, climate change may have a major effect on electric production for the Upper Colorado River Basin, affecting reservoirs such as Ruedi. While interannual precipitation amounts vary greatly year to year, trends in maximum SWE and total annual precipitation since 1981 above Ruedi Reservoir are relatively flat based upon the Kiln SNOTEL site data. If precipitation remains about the same as recent decades, rising temperatures will still alter runoff. Model estimates show that for a 1.8ºF (1.0ºC) increase in temperature there is about a 3% to 10% decrease in runoff.[103] Other model analyses indicate the importance of precipitation as well: for a 10% reduction in precipitation there is a corresponding 20% reduction in runoff. In this work, estimates for the Upper Basin in the case of a 2ºC increase in temperature by 2050 indicate a decrease in runoff on the order of 4-18%. These long-term effects, coupled with annual and inter-annual variability, will offer new challenges to hydroelectric managers.[104]

Figure 4.5 Electricity production and snowpack above Ruedi Reservoir

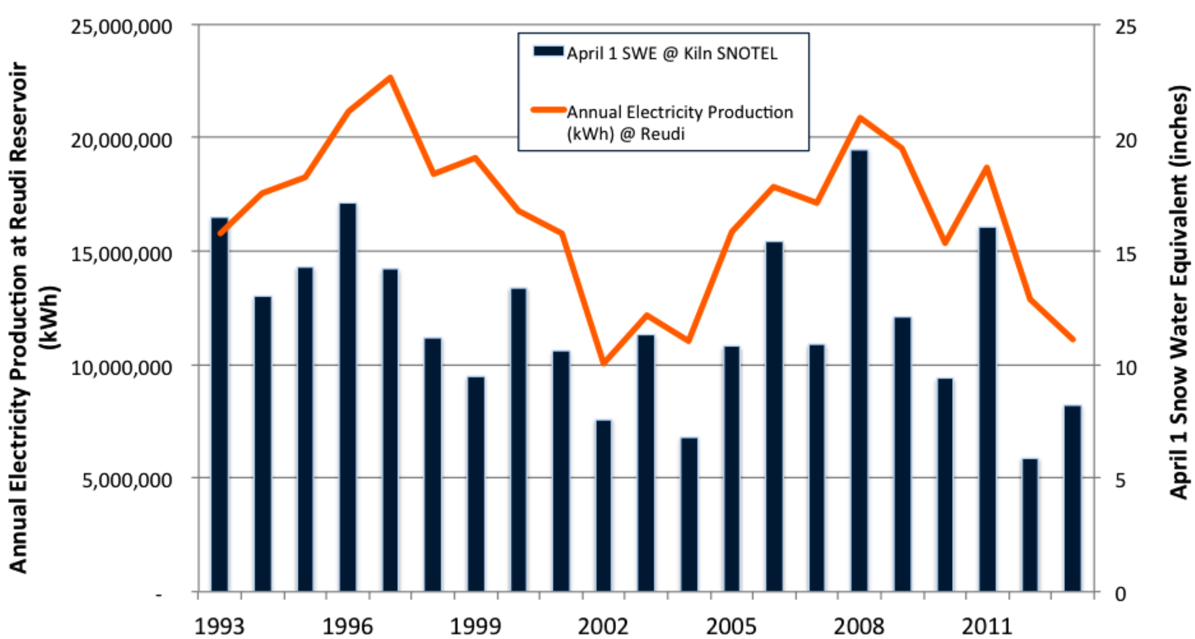

Figure 4.5 shows annual electricity production at Ruedi Reservoir alongside snow water equivalent measurements taken on April 1 each year at the Kiln SNOTEL monitoring site. Although the April 1st measurement is only a proxy for Ruedi reservoir water supply, the correlation between annual production and April snowpack highlights the connection between climate variability and renewable energy production in the Roaring Fork Valley. Source: NRCS SNOTEL and City of Aspen.

[103] Vano et al. 2014

[104] Hoerling, M., D. Lettenmaier, D. Cayan and B. Udall. 2009. Reconciling Projections of Colorado River Streamflow. *Southwest Hydrology* 31.

Energy demand implications

Aspen's changing climate will affect the nature and timing of energy demand, particularly the heating and cooling demand in area buildings. The following subchapter on infrastructure and the built environment presents projections for heating and cooling degree days by mid-21st century. Since energy for cooling is predominantly provided by electricity, whereas energy for heating is mainly provided by natural gas, both the timing and overall annual electricity demand will change. Rising temperatures lead to more cooling days, which in turn means a rise in summer electricity demand. This shift in the nature of energy demand, along with anticipated increases in population, places an even greater burden on regional and municipal efforts to reduce energy demand through efficiency improvements and to lower the carbon intensity of energy use.

Climate risks to national and international energy supply

Aspen's tourism-based economy relies on a national and international energy infrastructure to provide reliable and affordable energy, particularly for the sources utilized to transport visitors by air or ground. In addition to alterations to hydropower production beyond the Roaring Fork Valley, a number of other climate related outcomes may impact global energy supply including:[105]

- Energy production curtailed regionally and nationally due to water, temperature, and supply constraints
- Direct impact on production due to extreme events
- Sea level rise damage to existing energy infrastructure and impairment of new energy infrastructure

Aspen's exposure to this impact may be limited due to the affluent profile of visitors coming to Aspen. Many visitors may be able to absorb even significant changes in the price of energy—either at home or for travel—and may also be able to manage short-term drops in energy reliability.

Response strategies

Responding to the potential impact of climate change on Aspen's energy resources will require more site-specific study of local energy sources. In addition to potential impacts of climate change on energy supply, changes in timing and in overall quantity of energy demand and non-climate drivers such as population growth may also be worth consideration. Strategies that

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[105] USGCRP 2009.

Box 4.5 Energy summary

Climate-related Changes:
- Increasing summertime high temperatures
- Warming wintertime minimum temperatures
- Alterations to snowpack and timing and quantity of runoff

Future Potential Impacts
- Uncertainty of future dependability of energy sources, such as hydroelectric
- Increase in cooling load and reduction in heating load demand in buildings
- Climate-related risks to national and international energy supply

Potential Responses
- Development of site-specific evaluation of energy resource among future climate scenarios
- Diversification of location and type of renewables
- Integration of demand side management and GHG reduction strategies in energy resiliency planning

Opportunities
- Code requirements for greater building efficiency, reduced carbon emissions
- Reduction in heating degree days and increase in cooling degree days may smooth out annual energy demand curve for Aspen's utility, currently a "winter-peaking" utility
- City of Aspen electric and Holy Cross Energy can incorporate future climate projections in their supply and demand planning, particularly in relation to the anticipated increase in renewable sources
- Aging infrastructure replacement can incorporate future climate projections in design standards (road, runway, bridge abutments, power system capacity, etc.)

Lingering Uncertainties
- System effects of electricity becoming a greater share of total energy supply
- Extent of additional annual and seasonal alteration of solar and wind resources
- Effect of future trends in precipitation, streamflow, and water storage on hydroelectric potential

enhance resiliency may include reducing vulnerability to sudden local changes in climate and hydrological conditions by acquiring a more diverse source of energy production capacity within and beyond the Roaring Fork Valley.

The City of Aspen Electric utility has a progressive approach of acquiring a high percentage of its electricity from renewables with the goal of achieving 100 percent. The portion of the upper valley supplied by Holy Cross Energy is operating under the Colorado Renewable Portfolio goals. Both utilities have active programs on the demand side to increase efficiency. In addition, the Community Office of Resource Efficiency provides incentives for renewables combined with audits and efficiency upgrade incentives. Evaluating these programs anew in light of how climate change can affect supply and demand in the coming years will further these programs while building greater resiliency.

Under the guidance of the City's Canary Initiative, a carbon inventory was initiated and subsequently updated. This set of studies points to transportation as the major contributor to Aspen's total greenhouse gas emissions. On this front, a mass transit bus system (RFTA) has been successful in reducing individual vehicle use and in abating congestion valley-wide; however, in general the fuels component of energy use has been more problematic in achieving overall reductions compared to electricity. Fuels are a global commodity, so the question of reliable fuel supply is tied to how climate change affects global supply. Continued dialog that explores overall valley, community, and neighborhood design, combined with understanding of present and desired social frameworks for lifestyle and work, can alter transportation requirements and potentially reduce present and future dependence on fossil fuels for mobility while reducing vulnerability to external factors in fuel markets.

Less research has focused on how climate change will affect the transportation sector than how it will affect electricity supply, but there is ample research on the relationship between climate change and the built environment, particularly in relation to heating and cooling loads — Aspen's largest source of greenhouse gas emissions after transportation and electricity.

INFRASTRUCTURE & THE BUILT ENVIRONMENT

As average and extreme climate and weather trends continue to change, significant and potentially costly impacts are expected for residential, commercial, and public buildings as well as transportation, utility, and other infrastructures that connect and provide services to the community.[106] Design criteria that respond to changing climate-related risks can accrue numerous societal co-benefits, such as improved service reliability, comfort, and public health, while hardening critical assets to extreme weather events.[107] Resiliency planning with respect to infrastructure and the built involvement may include the following efforts:

- Building code review and revision
- Planning and design of new buildings or infrastructure investments
- Remodeling or replacement of existing assets

Many of the climate change related impacts to the built environment and infrastructure, such as fire, flooding, and landslide, also exist under normal climate conditions, and their importance is already reflected in regional planning documents such as the *Pitkin County Pre-Disaster*

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[106] U.S. Global Change Research Program (USGCRP). 2009. Global Climate Change Impacts in the United States. (T. Karl, J. Melillo, & T. Peterson, Eds.). Washington, DC. Http://library.globalchange.gov/products/assessments/2009-national-climate-assessment/2009-global-climate-change-impacts-in-the-united-states.

[107] Younger, M., H.R. Morrow-Almeida, S.M. Vindigni, and A.L. Dannenberg. 2008. The built environment, climate change, and health: opportunities for co-benefits. *American Journal of Preventive Medicine 35* (5): 517–26. doi:10.1016/j.amepre.2008.08.017

Mitigation Plan Update (2012).[108] However, climate change will shift the probability of some of these events and warrant further evolution of codes and best practices.

Changes to heating and cooling requirements

Climate trends in Aspen's recent past indicate relatively dramatic increases in minimum temperatures on a diurnal and monthly basis, along with an overall gradual increase in average annual temperature (see Chapter 2). Projections for Aspen and the surrounding regions indicate continuation of these trends. One result of these shifts that is relevant to the built environment will be an overall decrease in the heating load requirements of buildings and an increase in cooling requirements.[109]

> "Infrastructure designed to handle past variations in climate can instill a false confidence in its ability to handle future changes."
> -U.S. Global Change Research Program, 2009

Downscaled climate projections prepared by the USGS indicate a potential reduction of approximately 1500-2000 heating degree days per year and an increase of cooling degree days by approximately 300 degree days by the middle of the century under high emissions assumptions.[110] Figures 4.6a and 4.6b map out these potential changes for Aspen and the surrounding region.

For some buildings already equipped with heating and cooling systems, this shift may require only modest adjustment. However, for many Aspen buildings only equipped with heating systems, more days per year with high temperatures above tolerable comfort zones could involve significant capital investment to install cooling systems through retrofit. Although some owners may opt for behavioral changes or the "grin and bear it" approach, facilities designed to accommodate tourists or less adaptable clientele will likely be encouraged to ensure adequate cooling capacity. Smart design utilizing passive heating and cooling with appropriate efficiency attributes of building envelopes, can often achieve the comfort zone desired without additional energy requirements and even achieve energy reductions.

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108 Pitkin County. 2012. Pre-Disaster Mitigation Plan Update. 04 January 2012. Available at http://www.dhsem.state.co.us/sites/default/files/Pitkin%20County%204.2006.pdf

109 Bureau of Reclamation. 2013. Literature Synthesis on Climate Change Implications for Water and Environmental Resources. *Technical Memorandum 86-68210-2013-06*. Denver, CO. Available at http://www.usbr.gov/climate/docs/ClimateChangeLiteratureSynthesis3.pdf

110 USGS. Derived Downscaled Climate Projection Portal. Last updated April 20, 2014. http://cida.usgs.gov/climate/derivative/

Figure 4.6a Projected change in heating degree days

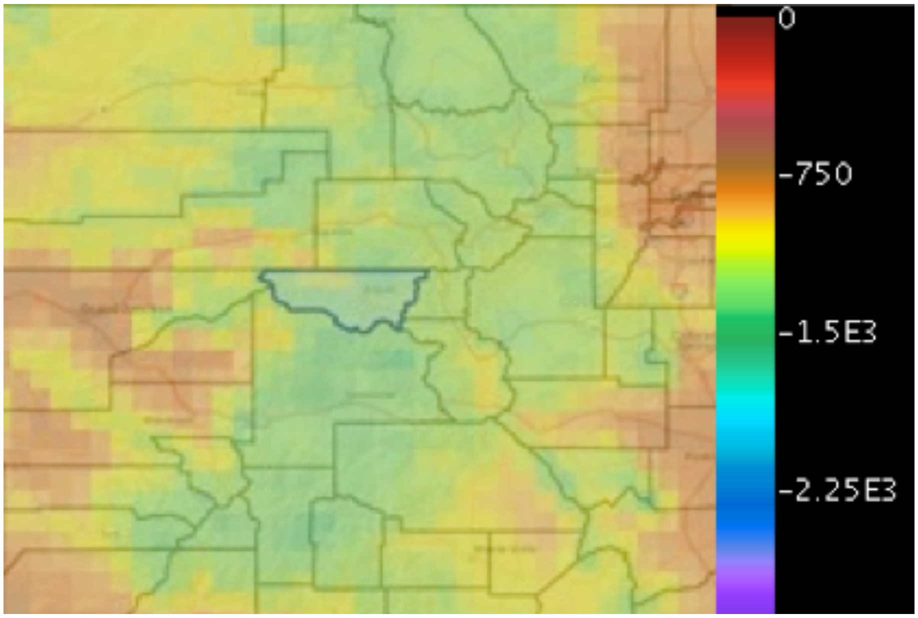

Figure 4.6b. Projected change in cooling degree days

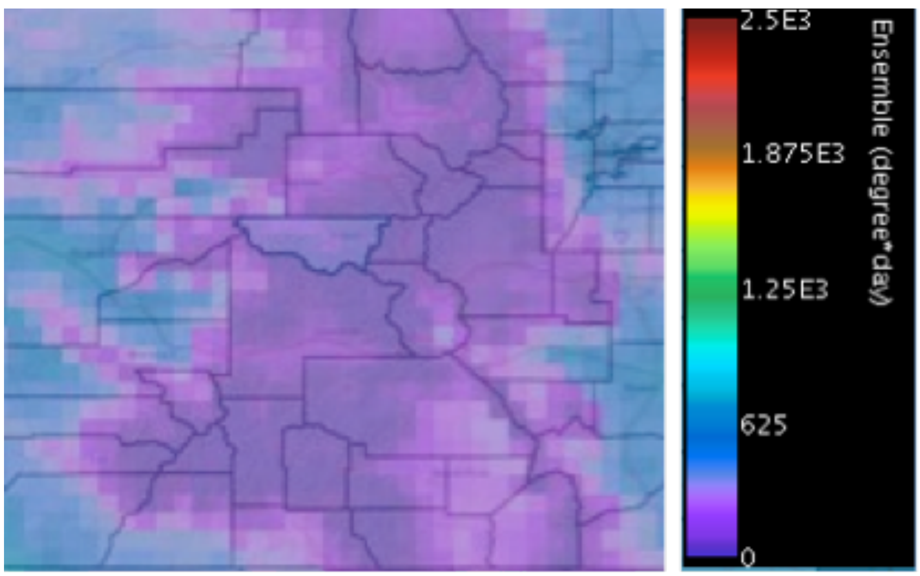

Figure 4.6a shows change in heating degree days per year for the projection period 2041-2070 using an ensemble of models running on the IPCC SRES A1FI (high) emissions scenario. Pitkin County is outlined in blue. Heating degree days for the area surrounding Aspen are expected to decrease (see color legend for approximate values) relative to 1960-1999 modeled values. The Degree Day Threshold is at 65.0ºF (18.3ºC). **Figure 4.6b** shows change in cooling degree days per year for the projection period 2041-2070 using an ensemble of climate models running on the IPCC SRES A1FI emissions scenario. Pitkin County is outlined in blue. Cooling degree days for the surrounding area are expected to increase (see color legend for approximate values) relative to 1960-1999 values. Threshold considered is 65ºF (18.3ºC). Source: USGS Derived Downscaled Climate Projection Portal.

Figure 4.7a Projected continuous dry days for Pitkin County

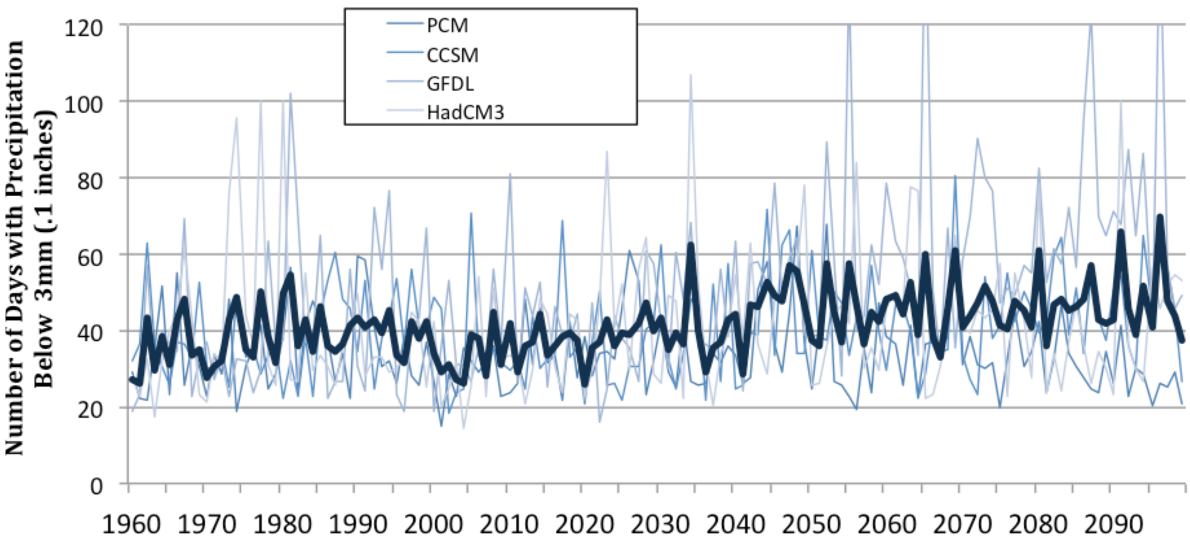

Figure 4.7b Modeled heavy rain in Pitkin County

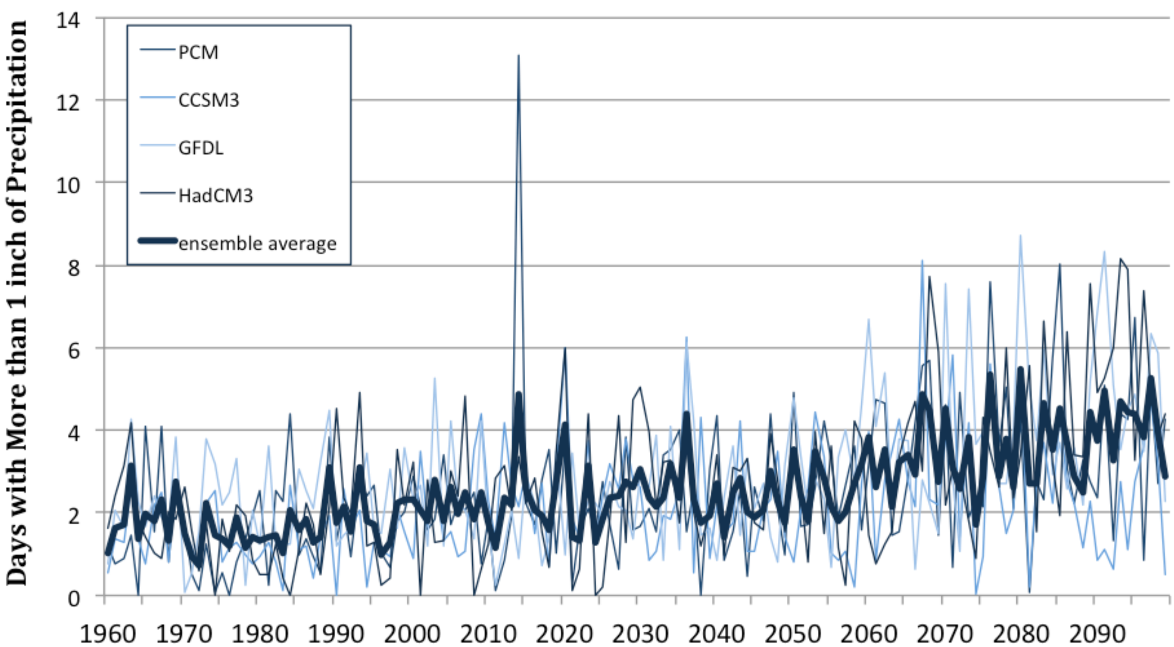

Figure 4.7a shows an increase in the length of the longest period each year receiving less that 3mm (0.1 inch) of precipitation under a high emissions scenario (A1FI). The average number of modeled dry days per year between 1960-1969 was 38.5. By the middle of the century (2040-2069), projections show this number increasing to 45.7 and by the end of the century (2080-2099) 47.9. Figure 4.7b shows an increase in the number of days receiving greater than one inch of precipitation projected for Pitkin County. Model results present downscaled multi-model CMIP3 data that assess the number of days receiving more than 1 inch of precipitation under a high emissions scenario (A1FI). The average heavy rain days for the modeled period 1960-1969 was 1.7. By the middle of the century (2040-2069), the projected number of days with heavy rain increases to 2.7, and by the end of the century (2080-2099) 3.9. Source: USGS Derived Downscaled Climate Projection Portal.

Impacts from extreme events

Aspen's location alongside the Roaring Fork River, large tracts of forest, and steep hillsides poses significant risk of flood, fire, landslide, and mudflow. Existing pre-disaster planning acknowledges these risks but does not take into account the effects of a future changing climate.[111] Assessing the likelihood of future flood and fire risk is confounded by uncertainty in the projection of the magnitude and timing of future hazards, particularly projections of changing extremes in precipitation—or lack thereof—that are most relevant for identifying flood, fire, and landslide risk, in addition to the more prolonged impacts of drought.

Modeling products derived from downscaled climate projections under high emissions scenarios project an increased number of days of heavy precipitation as well as longer dry spells with little or no precipitation. These regional model results suggest a shift in the type of extreme climate events Aspen may experience — a shift from what was considered normal during the 20th century. Figures 4.7a and 4.7b project both an increase in the number of heavy rain days and an increase in the duration of consecutive days receiving little (under 3mm) to no precipitation. This finding is consistent with general expectations of climate change where precipitation, regardless of overall quantity, will come less frequently but in heavier amounts. In other words, when it rains, it pours.[112]

Impacts associated with increased extremes in both dry periods and heavy rain events merits consideration in planning, design, and construction of buildings and infrastructure. In addition to floods, landslides and mudflows, other potentially destructive events associated with extreme precipitation have been identified as a key risk to settlement and society by the IPCC.[113] The Aspen area community is situated nearby numerous unstable geologic features such as alluvial fans, rock fall areas, and otherwise unstable slopes.[114]

Response strategies

Response strategies to climate-related risks posed to infrastructure and the built environment, as in other sectors, may involve a combination of efforts that assess site-specific risks for the purpose of (re)designing assets to reduce exposure or enhance resiliency. Review and reconsideration of existing building, energy, stormwater, and zoning regulations in the context of future climate risks could be one component of this iterative process.

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111 Pitkin County 2012.

112 Madsen, T. and E. Figdor. 2007. When It Rains It Pours - Global Warming and the Rising Frequency of Extreme Precipitation in the U.S. Environment America Research and Policy Center. http://www.environmentamerica.org/uploads/oy/ws/oywshWAwZy-

113 IPCC WGII 2007.

114 WRC Engineering Inc. 2001. Storm Drainage Master Plan for the City of Aspen, CO. http://www.aspenpitkin.com/Portals/0/docs/City/engineering/stormwater/ Development/1963-20.pdf

Box 4.6 Infrastructure & Built Environment Summary

Climate-related Changes
- Shift in the magnitude of temperature and precipitation extremes
- Reduction in wintertime minimum temperatures; increase in maximum temperatures
- Alterations in timing of runoff and quantity of run-off

Future Potential Impacts
- Increase in hazards to structures and infrastructure from flood, fire, and drought
- Increase of buildings' demand in cooling load and reduction in heating load

Potential Responses
- Evaluation and possible revision of building codes and infrastructure standards that address changing hazard risk
- Further evaluation of preparedness and response to low probability, high consequence events (e.g. more catastrophic wildfires)
- Integration of resilience and GHG reduction efforts into planning of codes and energy-intensive infrastructure such as transportation

Opportunities
- Rationale for improved building design requirements; integrating development codes with long term climate mitigation goals
- Integrating additional stormwater and mudflow mitigation techniques into urban design projects and parks
- New infrastructure engineered for the range of likely future scenarios will be able to be in service longer, have greater resiliency to change, and require lower resource utilization

Lingering Uncertainties
- How to determine climate change related infrastructure investments compared to best practices based upon historical climate data

Collective action with private property owners to assess risk and devise strategies as well as consultation with regional, statewide, and federal agencies and resources may be beneficial in identifying pathways that involve collective action and shared risks. Insight from green infrastructure, architecture, and land planning that account for both environmental hazards to human development and potential impacts on the environment from infrastructure development may lead to more transformational strategies that enhance resiliency, preserve capital investments, and improve well-being and public health.

In terms of coming up with adaptive strategies for first-order single stressors such as a prolonged drought, there are often second and third order impacts to consider. With drought there are riparian habitat impacts and increased risk of fire. With fire, there is increased risk to human health and the built environment. Economic effects would include impacts to fishing and rafting recreation, available water for irrigation, etc. These multi-stress situations can have far deeper overall affects on the community and its resiliency when considered in total.

Another important factor in adaptation planning is that when climate related impacts fall within a manageable range their impacts are taken in stride with existing systems and responses; however, some impacts do not scale in a linear fashion, but rather reach thresholds which, when exceeded, break down a community's ability to cope.[115]

[115] Wilbanks, T.J., P. Kirshen, D. Quattrochi, P. Romero-Lankao, et al.. 2008. Effects of Global Change on Human Settlements. In: Analyses of the effects of global change on human health and welfare and human systems. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Gamble, J.L. (ed.),K.L. Ebi, F.G. Sussman, T.J. Wilbanks, (Authors)]. U.S. Environmental Protection Agency, Washington, DC, USA: 89–109.

CHAPTER 5: STAKEHOLDER INTERVIEWS

For the purpose of gaining insight from the Aspen community on climate change impacts and potential responses, AGCI and the City of Aspen conducted interviews with 11 local stakeholders. These interviews constituted a preliminary round of engagement, and were intended as a precursor to other future opportunities for community involvement in resiliency plan development.

Stakeholders interviewed included City of Aspen and Pitkin County administrators, local business owners, resource managers, conservation planners and advocates, and other professionals working in sectors considered in this study.[116] Although the group interviewed represents a selection of local experts with sustained connections to the Roaring Fork Valley and deep involvement with and knowledge of their sectors, some of the observations and perspectives described in the following pages are anecdotal or based on personal opinion.[117]

During the semi-structured interviews conducted with community members, questions focused on:

- Existing decision-making and management activities within his/her sector
- Vulnerabilities within the sector including but not limited to climate change
- Observations of climate change at a local level and associated impacts

[116] With thanks to the following for participating in stakeholder interviews: **Richard Burkley** (Aspen Skiing Company), **Debbie Braun** (Aspen Chamber Resort Association), **Steve Barwick** (City of Aspen), **Sharon Clarke** (Roaring Fork Conservancy), **Jeff Dickinson** (Energy and Sustainable Design Inc. and Biospaces Inc.), **Mark Fuller** (Ruedi Water and Power Authority), **Boots Ferguson** (Holland and Hart), **Bob Harris** (formerly, Blazing Adventures), **Jonathan Lowsky** (Colorado Wildlife Science), **Barry Mink, M.D.** (Aspen Valley Hospital), and **Gary Tennenbaum** (Pitkin County).

[117] Please note that these descriptions depict the opinions and observations of individual stakeholders and are independent of findings or opinions of the Aspen Global Change Institute.

- Expectations of future climate change at a local level and anticipated impacts
- Actions undertaken or contemplated in response to climate change

Throughout these interviews, concerns about climate change as well as other challenges such as population growth, development, and economic stability came to the surface. These concerns provided insight into perception of the challenge of climate change in the context of many other competing priorities. As a result, the interviews illuminated opportunities for actions in response to climate change to occur alongside or in support of existing activities and initiatives.

Full transcripts of interviews are provided to the City of Aspen as a supplement to this report. Based on the agreement with the interviewees, these transcripts are confidential.

Box 5.1 Local changes or impacts identified by stakeholders:

- Drought conditions are more common
- Seasonal weather patterns are less predictable
- Earlier onset of spring
- Decreasing winter snowpack
- Reduction in extreme cold winter temperatures
- Species shifts in plant and animal communities, especially birds

Changes observed in local climate and associated impacts

Stakeholders interviewed were asked about changes they have observed that they believe may relate to climate change. All those who were surveyed were able to identify changes they thought were significant, although many were uncertain as to the extent that the changes were caused by climate shifts. The most common stakeholder observations related to increases in temperature, such as an early onset to spring. Many stakeholders noted that in the past timing and behavior of different seasons were more predictable, but more recently, as one stakeholder described, “The norm is to have dramatic fluctuations.”

Some interviewees linked temperature and seasonal shifts to changes in plant or animal behavior and presence in the Aspen area. Other stakeholders noted the implication of a longer summer might have on increasing the season for recreational activities such as mountain biking —opportunities that may pose challenges to protection of natural resources, including wildlife.

“There are species that are shifting northward at the same time that there are species shifting upward, and there are some species that are shifting northward and upward.”

The second most common observed changes were those related to precipitation and water availability, such as decreased winter snowpack or summer drought conditions. Many stakeholders spoke vividly about the recent 2002, 2011, and 2012 droughts as examples of conditions that may be more frequent in the future. The impacts of droughts were perceived to be far-reaching and included: high fire risk, damages to riparian systems, and alterations to winter and summer recreational amenities such as skiing or rafting conditions.

One hopeful observation made by several stakeholders was the expression of a sense that public awareness of climate-related issues has increased over the last decade.

> Box 5.2 Actions identified by stakeholders as already in progress:
>
> - Water efficiency planning and riparian health management (e.g. Roaring Fork Watershed Plan)
> - Improved operational speed and flexibility for snowmaking
> - Wildfire hazard mitigation and response capacity
> - Implementing "green" building codes
> - Adjusting timing, size, and location of commercial rafting trips
> - Expanding attractions for tourists during early winter and shoulder season

Current & future vulnerabilities

Stakeholders interviewed were asked about current and future vulnerabilities to the sector in which they operate. Across the stakeholders interviewed, many mentioned the same vulnerabilities as a primary concern.

Top on the list of stakeholder concerns was water supply. Specific concerns included worry about potential droughts; decreases in precipitation; and increased calls for water locally, in the arid west, and through Front Range diversions. In addition to concerns about water availability, current water laws were viewed as inadequate to address future pressures to the supply, which stem from the combined pressures of population growth and climate change.

Concern over future water availability was mentioned by 10 of 11 stakeholders, many of whom used markedly negative words like "water fights" or "water wars." As an interesting point of comparison, water was also identified at the 2005 town hall meetings during the development phase of the 2006 Study as the most critical factor related to climate change for the valley.

> "One of the things that really scares me right now is that the state has at least 600,000 acres feet of a [water] gap that they figure [means] we won't have enough water with population growth."

The next most common vulnerability cited by stakeholders was population growth at a local, state, regional, and global level. Population was mentioned by 8 of 11 stakeholders, with reasons for concern varying from increased pressure on limited resources to local expansion of development and heavier recreation influence on wildlife areas, increased demand for energy, or greater opportunity for the spread of disease.

The third most cited vulnerability was increased wildfire risk from increasing temperatures, drier conditions, and an expanding urban-wildlife interface.

Actions underway

Stakeholders were asked about actions they are already undertaking in response to changes in climate, if any. In the responses, activities that were mentioned typically involved responses that addressed other vulnerabilities as well. For example, the Watershed Action Plan (2012), a collaborative watershed-scale strategy that many interviewees participate in, includes climate change as one of many issues of concern in riparian health and management.[118]

"What we've learned is that it's beneficial to go slow to go fast. Spend a lot of time with the public engagement and input up front, and then it makes implementation a lot smoother and more efficient."

Desired future actions

Even across diverse perceptions of which vulnerabilities are most important, common themes emerged in the type of actions stakeholders recommended. Most frequent was a desire for early planning and discussion that begins before conflicts emerge, particularly in relation to water and fire concerns. Multiple stakeholders also mentioned the importance of long-term monitoring and public outreach.

In addition to describing the types of actions they believe are necessary to help meet changes associated with an altered climate, stakeholders also described current actions that they believe to be beneficial. Actions or changes mentioned by at least two different stakeholders included: increased public awareness of the issues, greater local production of food, upgrades to fire fighting infrastructure, movement toward leave-in-stream water usage rights, community outreach, and creating collaboration among multiple groups and organizations.

Box 5.3 Desired future actions identified by stakeholders:

- Public education
- Flexibility in planning and action
- Crisis plans
- Water conservation planning
- Reconsideration of current water laws
- Local food production
- Building codes in relation to fire protection and energy use
- Long term monitoring

Constraints

When asked about barriers to desired and current actions, the three top answers were cost, politics, and public awareness, followed by the challenge of addressing water allocation conflicts using current water laws. Other constraints described included: lack of public awareness or interest, technical limitations, concern over industry sway in law-making, and the

118 http://www.roaringfork.org/sitepages/pid362.php for access to the Roaring Fork Watershed Plan and climate related actions.

need to promote issues in a way that does not make one-sided good or bad value statements about the issues or different points of view involved.

"How do you know? You don't. And yet, you're foolish to go into the future with your eyes closed."

Several other indirect constraints to resiliency planning were common to many of the stakeholders interviewed. One of these constraints was the uncertainty associated with climate projections. As one interviewee put it, "I hate planning for things that I really don't know are going to happen, and that's what's difficult right now." Several stakeholders cited conflicting or changing results in model projections for the region as contributing to their uncertainty about what future changes to expect.

Another barrier to resiliency planning that emerged during the interviews was a mismatch between many stakeholders' typical planning horizon and the planning horizon of climate models. For stakeholders in governmental roles or connected with water supply issues, some planning consisted of timescales up to fifty years in the future, but for many stakeholders, particularly in the private sector, planning horizons were as short as daily and typically were no longer than 10 years. Discussion about climate change impacts 20 or more years in the future are not immediately relevant to the decision-making time horizon of many individuals, local groups, and businesses.

Conclusions

Box 5.4 Timescales for planning described by stakeholders.

- "99% of the time I was thinking about the next 20 minutes! There was no 5-year strategy plan."
- "Most of the time it is immediate stress or duress [of] large capital investments… [we have] a three-year strategic plan."
- "When we do our annual goal setting process…they're usually talking long term, which could be 5, 10, or multi-decade type of issues."
- "… we try and anticipate what projects we think we need to complete in 10 year increments."
- "In the water work that I do, I am not thinking in particular of a period of years, but I would say long term. A lot of the water clients have to think out 50 years, water supply for 50 years."

On a rating scale of 1-10, with 10 being the most concerned, stakeholder concern about climate change ranged everywhere from a 4 to a 10. The longer the time frame discussed, the greater the concern, particularly for stakeholders who have children. The types of concerns described and the context of the concerns for stakeholders often overflowed the bounds of ecological changes, highlighting an important consideration in adaptation planning: the changes that will occur as a result of climate change will not happen in a static environment. These changes will interact with and be influenced by the political, social, and population dynamics of the future. Plans for climate adaptation therefore must take these parameters, particularly the likelihood of population growth, into serious consideration.

CHAPTER 6: PRELIMINARY GUIDANCE FOR RESILIENCY PLANNING

Box 6.1 Resiliency planning key points

- A variety of motivations drive individuals and groups to engage in resiliency planning and implementation
- Planning to increase resiliency requires an iterative, collaborative, and ongoing process
- Multiple pathways exist to reduce risk and enhance resiliency
- Considering multiple criteria when defining goals and objectives is possible
- Continuous stakeholder engagement and involvement is a critical component

As stated in the introduction to this report, the purpose of this study is to inform the City in its pursuit of climate resiliency planning. In this section we provide preliminary guidance for resiliency planning efforts, which are intended to support adaptation to climate risks by individuals, groups, and the community-at-large across sectors.

Motivations for resiliency planning

Society at different levels of organization, from individuals to businesses and from cities to nations, will almost certainly face some climate-related changes. These encounters may be realized as either costs or benefits, depending on the nature of change, vulnerability, and exposure, as well as response capacity.

Motivations to engage in resiliency planning will vary given the heterogeneous nature of impacts and ability or willingness to consider scenarios of change in future planning and decision-making. In addition, different elements of society have various responsibilities to uphold, whether they be obligations to constituents, rate payers, shareholders, owners, family members, or neighbors. Awareness of the range of actual or potential motivations enables those who spearhead resiliency planning within a community to facilitate a more inclusive, robust, and transparent planning process.

Examples of motivations:

- **Municipal and regional government motivations**
    - Providing for long-term health, safety, and well-being of the community
    - Continuity of essential services (e.g. utilities, emergency response)
    - Supporting economic and cultural growth of the community
    - Avoiding costly damages from climate-related events

- **Business and non-profit motivations**
    - Maintaining the continuity of operations and missions
    - Avoiding costly damages from climate-related events
    - Identifying and exploiting new opportunities

- **Individual motivations**
    - Preservation of community, local values, and culture
    - Avoiding costly damages from climate-related events
    - Participating in and contributing to civic process
    - Civic ownership in working toward a healthy, resilient and sustainable community

Adaptation planning process

Figure 1.1, presented in Chapter 1, depicts adaptation as one component of local resiliency capacity. Figure 6.1 further describes the process of adaptation planning and illustrates it as an iterative, ongoing cycle. As progress is made in building resiliency, this process is renewed with another cycle of assessment, action, and evaluation. While this idealized and simplified model does not necessarily capture the exact order or all component parts of adaptation in actual practice, the essential point is that adaptation is a continuous process of learning, planning, implementing, and evaluating. One key attribute of this process is that to be successful it goes beyond a planning process into the realization of changes to policies, operational procedures, infrastructure, and the fabric and awareness of the community. The component parts of Figure 6.1 are:

- **Learning & Assessment**: Preparing to adapt begins with understanding local context and identifying risks pertinent to that locality. This involves an integrated assessment of physical, ecological, and societal impacts both currently and in the future and the ability to incorporate new information about impacts and adaptation options over time.

- **Planning & Engagement:** Armed with the best-available relevant information and understanding of the profile of risks pertinent to the community, individuals and groups begin developing strategies to reduce impacts or exploit beneficial opportunities. This involves setting measurable goals. It also involves engagement of stakeholders who may be helpful in implementing these strategies as well as those groups that may be impacted, either positively or negatively, by the consequence of anticipated actions.

- **Implementation & Monitoring**: Implementation of proposed response strategies also incorporates a monitoring component to provide the data essential to analysis of performance measured against the established goals.

- **Evaluation:** The final stage identifies areas for improved process and implementation and charts the course for embedding learning before the initial "trip around the wheel" begins anew (see "Criteria for Success" below).

To make the process truly a cycle, the process begins again at step one with additional learning assessment and carries on through completion of the cycle. An example of this idealized process in action can be found in Keene, New Hampshire's Climate Resilient Communities Adaptation Planning Process which includes five milestones:[119]

- Conduct a climate resiliency study
- Prioritize areas for action and set goals
- Develop an adaptation action plan
- Implement the action plan
- Monitor, evaluate, and update the plan

Types of response

Adaptation involves a suite of actions undertaken by individuals, groups, and governments, both autonomously and in response to policy. It is important to recognize that there are multiple types of responses to consider when formulating response strategies. While the exact set of responses will vary depending on the risks confronted and the options available, consideration of the full range of options allows individuals and the community as a whole to strategically invest in and pursue actions that most effectively mitigate risk while also maximizing opportunities or aligning with co-benefits. It is important to note that adaptation measures are

[119] City of Keene New Hampshire and ICLEI. 2007. *Adapting to Climate Change : Planning a Climate Resilient Community November 2007*. Keene, New Hampshire.

often, if not always, implemented in response to multiple rationales, not just climate change alone.[120]

Table 6.1 illustrates that a variety of responses can be used to address a single issue. It presents six categories of response with potential examples for wildfire risk reduction. The responses are intended to serve as examples only and not as recommendations.

Figure 6.1 Adaptation planning for climate risk reduction

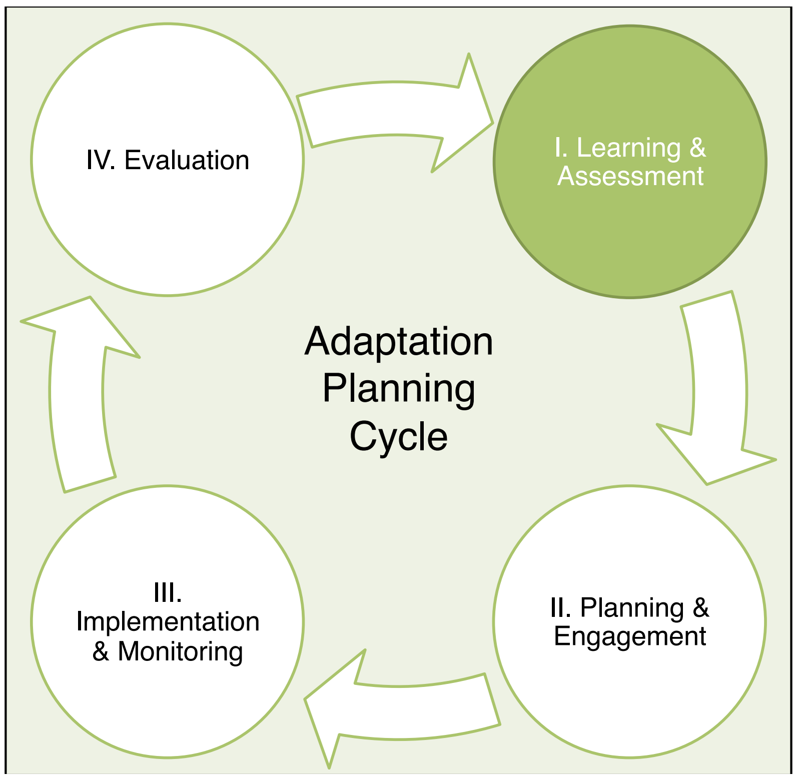

Figure 6.1 Planning in the context of change is often best supported by an adaptive planning process that is cyclical rather than linear and allows for learning and adjustment along the way. Initial learning and assessment (I) informs planning and initial engagement with the community (II). Plans are then implemented and long-term monitoring based on goals and objectives (III) enable evaluation. As learning takes place within the sectors of our community — what worked, what didn't and why — the adaptive management cycle begins anew building both goals of resiliency and sustainability.

Criteria for success

This chapter has stated that resiliency planning requires ongoing iteration based on ongoing learning, monitoring, evaluation, and adjustment to new information. While this is important, it

[120] Adger et al. 2007.

begs the question, what is an ideal future state to plan toward, and by what criteria is success measured?

Successful adaptation to climate change that enhances preparedness and promotes resiliency cannot be measured entirely by quantitative benchmarks, nor can it be evaluated by one dimension alone.

The following are criteria to consider, based upon descriptions of "successful adaptation" developed by researchers Susanne Moser and Maxwell Boykoff:[121]

Table 6.1 Categories of response for climate change risk reduction

Categories of response	Examples of actions with fire as case study
Reduce exposure	Relocating high value assets from at-risk areas; adjusting timing of activities during periods of potential impact
Response and recovery preparedness	Improving capacity of emergency responders and reducing recovery time between events
Increase resilience to changing risks	Ensuring continuity of critical services during and after event; post-event communication strategies for community and tourists
Reduce vulnerabilities	Developing resources that harden infrastructure and services to extreme events
Transfer and share risks	Promoting collaborative planning and action with stakeholders and neighboring governments
Transformation	Creating an integrated approach to mitigate underlying cause of risk while also coordinating resiliency enhancement and vulnerability reduction
Adapted from Moser & Boykoff, 2013	

- *Economic protection* – minimizing or avoiding losses from climate-related damages, while at the same time capitalizing on potential financial benefits

[121] Adapted from Moser and Boykoff 2013.

- *Institutional and policy adequacy and legitimacy* – preserving the ability of institutions and policies to meet obligations to residents/constituents as well as non-human systems (e.g. ecosystems)

- *Ecological and environmental protection* – preserving the resiliency capacity, diversity, and services made possible by health ecosystems and broader environmental conditions

- *Social justice* – reducing vulnerabilities and/or inequities within marginalized populations while strengthening communities and the well-being of all members

- *Political and procedural integrity* – supporting transparent and inclusive processes

- *Cultural and psychological factors* – preserving and/or enhancing vital aspects of community (e.g. the "Aspen idea")

Lessons from other communities

Table 6.2 compiles four examples of other communities—ranging from small to large—that have made steps (of varying length) towards climate resiliency planning.

Table 6.2 Selected examples of climate adaptation plans

Place	Date	Title	Helpful Feature	Link
Keene, NH	2007	Adapting to Climate Change : Planning a Climate Resilient Community	Outlines idealized framework for planning	Click here.
Boulder, CO	2012	Boulder County Climate Change Preparedness Plan	Allows for integration of guidance into existing departmental structure	Click here.
Moab, UT	2010	Forest and Water Climate Adaptation	Clearly defines goals, actions, and responsible parties	Click here.
King County, WA	2007, 2012	Climate Plan (2007); Strategic Climate Action Plan: What King County is Doing to Reduce GHG Emissions and Prepare for the Impacts of Climate Change (2012)	Integrates approaches for adaptation and mitigation and aims to be a leader in the field of climate planning. Also, contains update to see evolving structure.	2007: Click here. 2012: Click here.

More plans and resources from other communities may be searched through:

- Georgetown Climate Center: State and Local Adaptation Plans
    - http://www.georgetownclimate.org/adaptation/state-and-local-plans

- Climate Adaptation Knowledge Exchange (CAKEX)
    - http://www.cakex.org

Stakeholder engagement

Chapter 5 presents input and ideas gleaned from an early round of stakeholder interactions conducted for the purposes of this study.

These stakeholder interviews represent just one of many techniques for eliciting stakeholder participation, and multiple strategies will likely need to be pursued to capture the diversity of stakeholders and perspectives that exist. Examples of forums and mechanisms for gathering stakeholder input may include:

- In-depth stakeholder interviews
- Town hall meetings
- Public input forums
- Visitor/resident surveys
- Collaborative planning workshops and meetings
- Public outreach and education on key topics

CHAPTER 7: CONCLUSION

The observations, projections, and research presented here—as well as in other reports ranging from other local studies to international assessments—convey increasing confidence about climate change and its significant consequences for society and ecosystems. Taken together, this evidence impels communities large and small to think about preparations that build resiliency.

Aspen has the opportunity to lead in this arena, particularly among mountain resort communities, though it is likely that Aspen's efforts will move forward alongside many other communities considering similar actions. Mutual learning among communities is therefore likely to occur and may be a vital component in meeting objectives under an increasingly urgent timeline.

While uncertainty remains in many areas important to decision-making, there is now enough information to characterize a range of possible futures. Uncertainty may appear at first to be a barrier to action, but utilization of multiple scenarios and accommodating multiple future outcomes in planning and implementation has the potential to strengthen the overall security and sustainability of a community.

This report is a basis for future planning at the City of Aspen and the surrounding community. Any one of the issues raised in this study could be examined in more depth, either through exploring references included within the report or through additional research. It is likely that for some of the potential impacts, significantly more site-specific study and research is needed. As one example, evaluating changing risks from fire, flood, landslide, or drought requires detailed examination of local risk conditions and evaluation of existing response capacity and resilience. Only from such a specific basis of information could specific response strategies be adopted.

It is also recommended that careful attention be focused on stakeholder communication and engagement. A diversity of views, interests, and local expertise exists in the community and incorporating that breadth of knowledge into resiliency planning is likely to ensure more success during implementation.

Moving forward, there are several areas of research and resource development that could continue to support the resiliency planning process as it moves forward:

1. **Assessment of potential economic gains and losses resulting from projected impacts.** An early effort to look into the financial ramifications of climate change was conducted for the 2006 Study, but the findings were only very general. Analysis of economic drivers and their seasonal vulnerabilities in the context of climate change could inform fiscal planning and also serve as a basis to justify future investments in both mitigation of and adaptation to climate change.

2. **Development or adaption of interactive tools that support local decision-making**. Decision support tools, such as systems models or game strategies that consider possible scenarios, can help illustrate the interlinking effects of climate change and proposed responses in particular sectors of interest. Tools developed from other regions may be adaptable to the Aspen area as well as new resources developed specifically for Aspen.

3. **Wider assessment of climate-related impacts to the Roaring Fork Valley and opportunities for collaborative planning and implementation**. Climate impacts to Aspen will not happen in isolation from impacts felt throughout the Valley and surrounding region. Identifying areas where impacts beyond the Aspen community are similar to those likely to be experienced in Aspen could offer one extension of this study. Another area for further investigation could be impacts external to Aspen that may have local impacts. Collaboration with other communities within the Roaring Fork Valley may enable this type of work.

These types of activities could complement other efforts pursued by the City, such as engaging with networks of other communities pursuing resiliency planning, the Western Adaptation Alliance being one example. Over time, it is possible that adaptively managing for climate change will become a commonplace activity pursued routinely at the municipal level and integrated into many current departments.

Although much change is anticipated as a result of climate change in the coming years and decades, there is still time for society to address its underlying drivers as well as prepare for its many unavoidable effects. As a mountain resort, Aspen may very well feel the impacts of climate change more quickly and even more severely than other small communities, yet its longstanding leadership and aggressive action on this issue will help it to prepare and build resilience.

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Appendix A

Review of results from 2006 Study

In 2005, amid growing interest and concern in the Aspen area about climate change and its potential local impacts, AGCI was engaged by the City to assess climate change impacts and potential responses. The report helped to launch the Canary Initiative and engaged elected officials, citizens, and members of the scientific community. Town Hall meetings and stakeholder interviews revealed a growing concern about climate change and how it would affect water, skiing, summer tourism, agriculture, fire, invasive species, pest risk, and more.

Selected key findings from the 2006 Study include:

Climate Observations (1980-2004)

- Average temperatures in Aspen increased 3.0ºF
- Total precipitation has decreased 6%; snowfall decreased 16% at 10,600 feet; total precipitation decreased 17%
- Frost free period increased by 20 days

Climate Projections

- 2030: Average annual temperatures increase 3-4ºF from 1990 with the middle world greenhouse gas emissions scenario (SRES A1B)
- 2100: Projected temperatures increase as much as 16ºF for high emissions scenario (SRES A1FI)
- Projected precipitation change less certain; climate models indicate a possible mid-range decrease of 7% by 2030 (SRES A1B)
- The course of the world's current future greenhouse gas emissions scenario will significantly influence end-of-century projections for temperature and precipitation

Ecosystem Impacts

- Rising temperatures may render local coniferous forests vulnerable to insect infestation, especially to bark beetles

- Changes in climate may contribute to endangerment of “habitat specialists,” such as ptarmigan and pika
- CO_2 fertilization may promote growth in noxious weeds
- Shift in eco-zones from lower to higher elevations

Socioeconomic Impacts & Analysis

- Vulnerabilities of Aspen Skiing Company include under-target snowfall, curtailed ski season, altered perception of snow quality by tourists, and beginner hill degradation
- Resiliency assets of Aspen Skiing Company include: operations on four mountains, capacity for snowmaking, lift downloading to base, and financial resources
- Greater uncertainty in residential investments (e.g. 2nd home preferences)
- Potential to maintain better snow conditions than many competing resorts due to high elevation and relatively colder temperatures
- Three quarters of all spending in Aspen comes from visitor spending, and three quarters of winter visitor spending is directed toward skiing

Hydrology on the Roaring Fork River

- 2030 and 2100 projections among all scenarios considered show earlier peak runoff
- Increased challenges in meeting minimum stream flows
- Less water stored as snow, more annual precipitation as rain projected for the future.
- Projected higher temperatures may have greater effect on streamflow than projected minor changes in precipitation (due to snowmelt, sublimation, evaporation, and evapotranspiration)

Appendix B

Methodology and additional results from CMIP5 modeling

Methods

In the modeling studies included within the 2006 Study, Claudia Tebaldi and Linda Mearns from the National Center for Atmospheric Research utilized a Bayesian statistical technique to synthesize the information contained in an ensemble (collection) of different GCMs, run under historical and future scenarios, into probability distribution functions of projected temperature and precipitation change. In that work, the analysis was performed at a regional scale for four grid boxes surrounding Aspen, as shown in Figure B.1. This method's results are aimed at representing the expected signal of anthropogenic change (i.e. change induced by human sources of greenhouse gases and land use change). The actual climate at the times of these various projection horizons will reflect both the strength of this signal and the natural variability in the climate system that will be superimposed to it. The area represented by the grid boxes was chosen to reflect primarily the Western Slope and Colorado Plateau and the Upper Colorado River Basin. The analysis technique weighted model results based on convergence with other model results in the cohort as well as a bias adjustment for result proximity to observed results during the historical base period (1980-1999). The GCMs assessed in 2006 using this method were the 21 GCMs (20 for precipitation) conducted as part of the Coupled Model Intercomparison Project 3 (CMIP3), which were assessed in 2007 by the IPCC. Generally the climate models are improving in how well climate models can represent past climates, but how well models represent the past does not equate to how well features of the future climate will be captured. Multi-model ensembles are used in order to help better capture the range of uncertainty that exists when modeling future conditions

Figure B.1 Location of CMIP5 grid cells

Figure B.1 shows the region considered in the CMIP5 GCM model. Analysis of CMIP5 GCM model output was performed at a regional scale for 4 gridpoint surrounding Aspen, covering the area from 105.50W – 111.06° W and 36.30-41.84° N), as shown approximately above.

For this 2014 study, Claudia Tebaldi utilized the same method and grid cells as in 2006 but additionally analyzed results generated from a new generation of climate models. The results presented in this report assess results from 33 GCMs run as part of the Coupled Model Intercomparison Project 5 (CMIP5), which were recently assessed in 2013 by the IPCC.

Table B.1 Comparison of CMIP3 (2006 Study) to CMIP5 (2014 Study) results

2014 Results (CMIP5)						**2006 Results (CMIP3)**				
RCP 4.5 Temp Change (ºF) from 1980-1999 Average						B1 Temperature Change from 1980-1999 Average				
Time Period	DJF	MAM	JJA	SON		Time Period	DJF	MAM	JJA	SON
2020-2039	2.7	2.9	2.9	2.8		2000-2020	1.4	1.1	1.4	1.3
2050-2069	4.5	4.4	4.6	4.3		2040-2060	2.9	2.9	3.6	2.9
2080-2099	5.2	5.3	5.4	5.3		2080-2100	4.7	4.3	5.4	4.5
RCP 6.0 Temp Change from 1980-1999 Average						A1B Temperature Change (ºF) from 1980-1999 Average				
Time Period	DJF	MAM	JJA	SON		Time Period	DJF	MAM	JJA	SON
2020-2039	2.0	2.6	2.5	2.2		2000-2020	1.1	1.1	1.4	1.3
2050-2069	4.0	4.5	4.4	4.2		2040-2060	3.8	4.1	5.2	4.3
2080-2099	6.6	6.8	6.3	6.6		2080-2100	6.5	6.5	8.1	6.8
RCP 8.5 Temp Change (ºF) from 1980-1999 Average						A2 Temp Change from 1980-1999 Average				
Time Period	DJF	MAM	JJA	SON		Time Period	DJF	MAM	JJA	SON
2020-2039	2.8	2.9	3.1	2.9		2000-2020	1.1	1.1	1.4	1.4
2050-2069	6.0	5.9	6.5	6.3		2040-2060	3.6	3.8	4.9	4
2080-2099	9.3	9.1	10.5	10.1		2080-2100	7.4	8.1	9.9	8.5
RCP 4.5 Precip Change (% of 1980-1999 average)						B1 Precip Change				
Time Period	DJF	MAM	JJA	SON		Time Period	DJF	MAM	JJA	SON
2020-2039	4.8	-1.1	0.8	1.3		2000-2020	4.5	-0.9	-4.8	-0.1
2050-2069	4.6	1.3	1.6	2.1		2040-2060	3.9	-1.4	-5.5	2.6
2080-2099	6.4	1.1	2.4	2.3		2080-2100	5.9	-2.2	-4.5	0.6
RCP 6.0 Precip Change (% of 1980-1999 average)						A1B Precipitation Change (% of 1980-1999 average)				
Time Period	DJF	MAM	JJA	SON		Time Period	DJF	MAM	JJA	SON
2020-2039	1.9	2.2	-2.6	1.0		2000-2020	2.5	-1.9	-4.1	-0.7
2050-2069	4.1	3.7	1.0	-2.0		2040-2060	6.7	-4.7	-8.2	0.6
2080-2099	5.7	5.6	6.2	3.9		2080-2100	10.4	-7.5	-10.7	-0.5
RCP 8.5 Precip Change (% of 1980-1999 average)						A1FI Precipitation Change				
Time Period	DJF	MAM	JJA	SON		Time Period	DJF	MAM	JJA	SON
2020-2039	5.1	0.5	0.9	1.3		2000-2020	4.0	-0.7	-7.6	0.0
2050-2069	8.6	1.1	1.4	0.8		2040-2060	9.3	-6.1	-7.4	2.1
2080-2099	14.0	-0.1	0.8	1.9		2080-2100	11.8	-15.7	-8.4	6.3

Table B.1 2006 results were included in the AGCI 2006 Study and were provided by Tebaldi and Mearns. 2014 results reported on in this study utilized the same methodology (Tebaldi and Mearns, 2007) and were provided by Tebaldi. 2014 results utilize RCP emissions scenarios, similar but not identical to SRES scenarios utilized in 2006. Results are presented by three month groupings approximating the four season timeframes: DJF is December, January, February; MAM is May, April, May; JJA is June, July, August; SON is September, October, November. For precipitation, green highlighting indicates projected increases and red highlighting indicates projected decreases. On balance, 2014 results based on CMIP5 models indicate more positive precipitation results than 2005 results based on CMIP3.

Figure B.2. Projected temperature change in Western Colorado region by 2030 and 2090 (see caption after B.3)

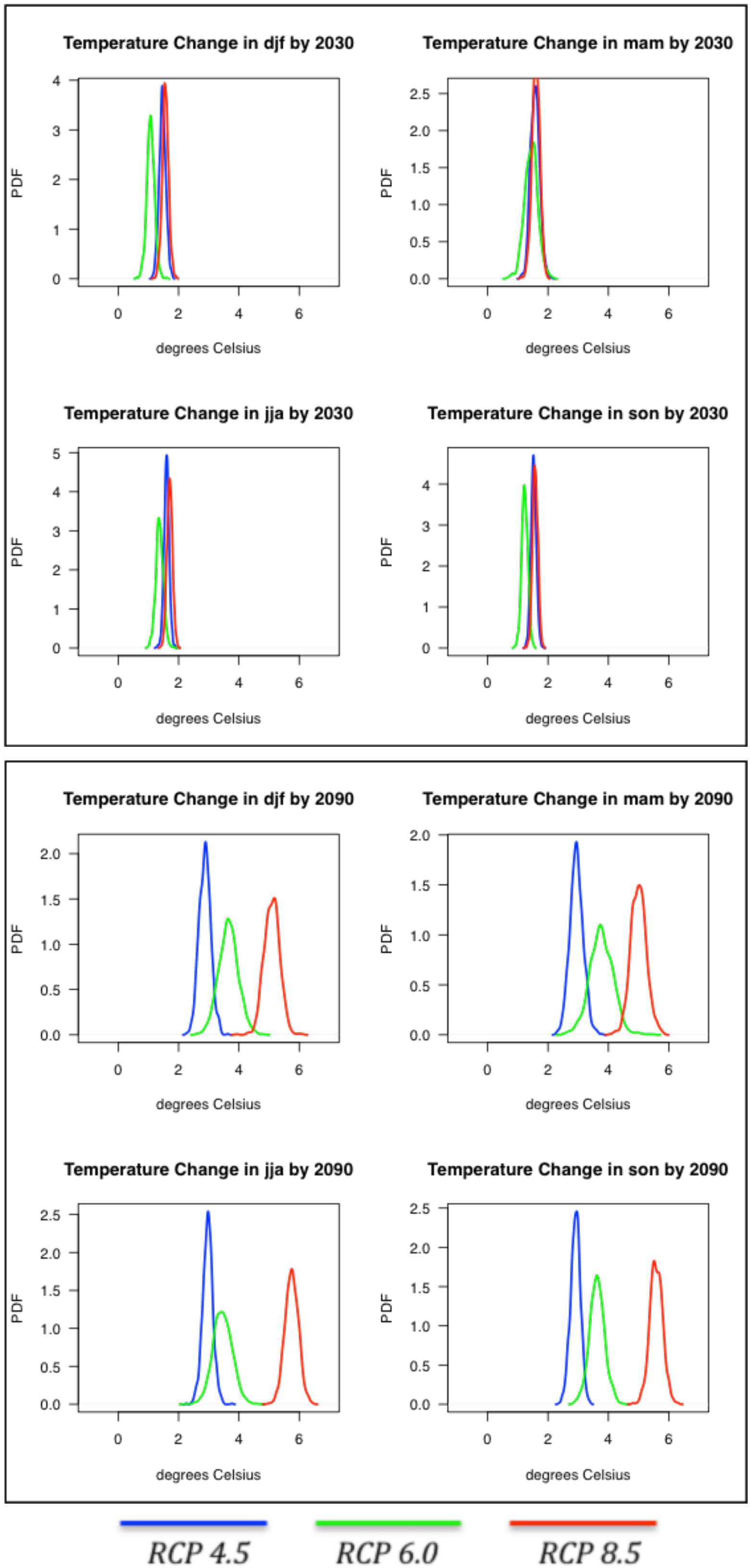
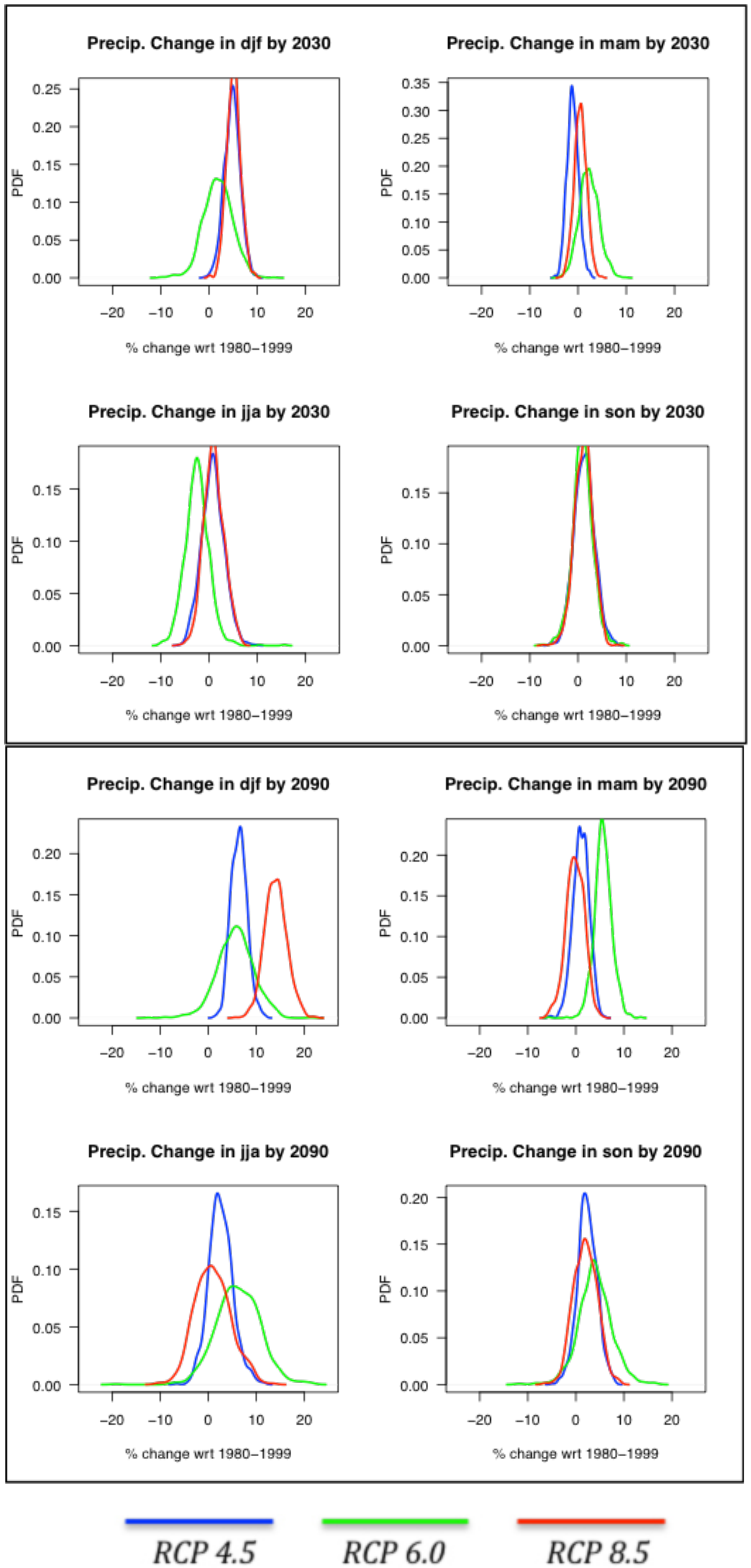


Figure B2. Projected precipitation change in Western Colorado region by 2030 and 2090 by season



Caption to Figure B.2 :

Figure B.2. shows probability distribution functions (PDFs) of projected temperature change for Western Slope region by future periods, seasons, and scenarios. Color coding indicates three emissions scenarios considered—RCP 4.5 (blue), a low emissions scenario comparable to B1 utilized in 2006; RCP 6.0 (green), a medium emissions scenario comparable to A1B used in 2006; and RCP 8.5 (red), a high emissions scenario comparable to A2 used in 2006. Results are presented by three month groupings approximating the four season timeframes: DJF is December, January, February; MAM is May, April, May; JJA is June, July, August; SON is September, October, November. Temperatures presented are in degrees Celsius difference between historical conditions observed 1980-1999.

Caption to Figure B.3:

Figure B.3 shows probability distribution functions (PDFs) of projected precipitation change for Western Colorado region. Color coding indicates three emissions scenarios considered—RCP 4.5 (blue), a low emissions scenario comparable to B1 utilized in 2006; RCP 6.0 (green), a medium emissions scenario comparable to A1B used in 2006; and RCP 8.5 (red), a high emissions scenario comparable to A2 used in 2006. Results are presented by three month groupings approximating the four season timeframes: DJF is December, January, February; MAM is May, April, May; JJA is June, July, August; SON is September, October, November.. Precipitation is represented as a percentage change from average conditions 1980-1999.