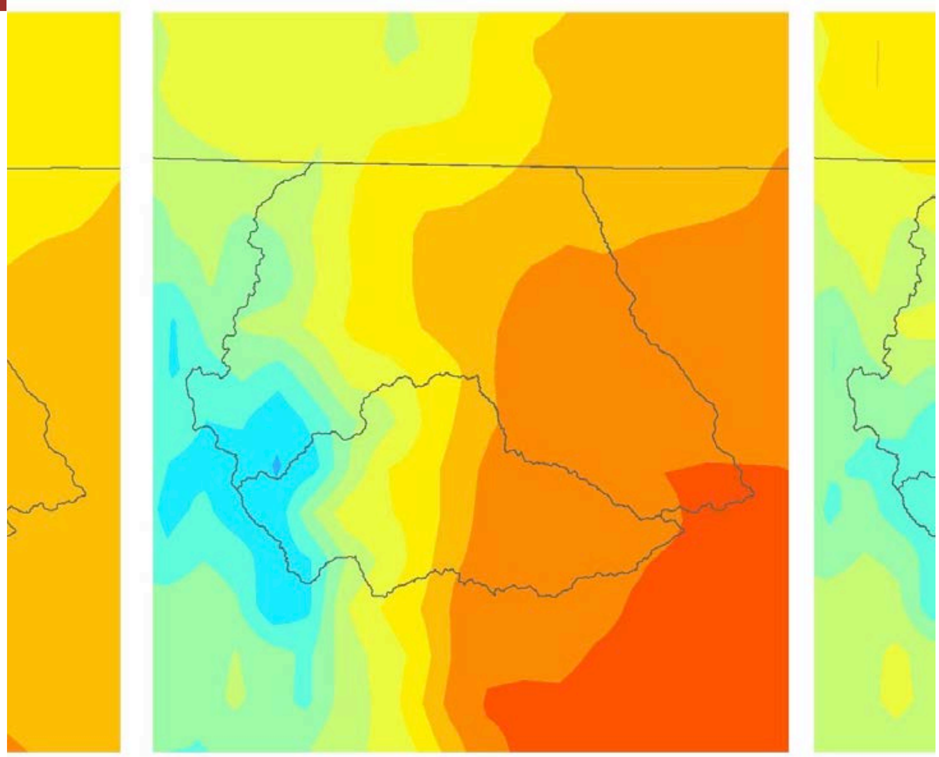
ClimateWise®

Helping communities prepare for a changing climate.

Climate Change Primer for Fort Collins, Colorado



November 2013

EXECUTIVE SUMMARY

The Front Range of Colorado has experienced much change over the last few decades. Future change may be even more striking. In addition to population growth, continued development, and economic diversification, the Front Range is expected to experience substantial impacts brought on by climate change.

Climate change has already been well documented throughout the western U.S. Average temperatures have risen 2-4°F over the last century. Rising temperatures have caused more precipitation to fall as rain instead of snow. Spring snowpack is lower throughout the western U.S., and the moisture content of the snowpack is also lower. Because the local climate is strongly influenced by the Pacific Decadal Oscillation (PDO), many impacts of climate change become heightened during the warm phase of this regional climate pattern.

Numerous changes to the hydrology of the Rocky Mountains have been documented, including increasing water temperature, declines in stream flow, increasing low flows, earlier spring runoff, and increased intensity and frequency of severe storms.

To better understand the impacts of climate change specific to Fort Collins, data from global climate models that have been adjusted to local scales were reviewed. A range of potential future conditions were developed based on that review. Potential changes to the climate and ecology of the region include:

Highly Likely Changes:

- Up to 6° F warmer summers by 2040
- Continued declines in snowpack
- Declines in soil moisture and water availability
- Lower and extended low stream flow in late summer
- Earlier spring runoff
- Greater likelihood of severe storms
- Greater likelihood of extended drought
- Shifts in wildlife and plant ranges
- Greater likelihood of severe wildfire, especially during warm phase PDO
- Increased spread of invasive species
- Increased frequency and severity of heat waves and ozone formation
- Increased pest and disease outbreaks, such as mountain pine beetle, West Nile virus, and chytrid fungus

Other Potential Changes:

- Up to 11° F warmer summers by 2070
- Increased winter precipitation
- Declines in aquatic species such as native trout and amphibians
- Declines in alpine and subalpine species, including subalpine fir, Engelmann spruce, pika, bighorn sheep, and others
- Shifts from subalpine to pine forests at higher elevations
- Loss of carbon storage in forests over longer time frames

The last two years have emphasized the vulnerability the Fort Collins community and its regional neighbors can experience due to extreme weather events. Because of events such as the High Park fire, the hottest year on record, and recent flooding, there has been substantial devastation to the region. To be proactive and prepared to protect and maintain our quality of life, Fort Collins must prepare for such future events and the potential for increases in severity and frequency due to a changing climate.

The City is currently undertaking an internal climate change adaptation planning initiative. During this planning, we will be developing a framework to enable City departments to incorporate climate change adaptation strategies into existing planning and asset management efforts, building off of work conducted in 2008 and 2011 to assess risks and vulnerabilities for Fort Collins Utilities. The overall objective of this initiative is to ensure our organization's ability to continue to provide municipal services in the context of changing climate patterns, while also ensuring continuity throughout our organization through climate change adaptation strategies.

This Climate Change Primer provides supporting information for managers and planners to begin to integrate climate change into their planning processes. Intended to inform a vulnerability assessment that will, in turn, drive the development of adaptation strategies, this report provides a basic background in the latest science specific to the Fort Collins area. As newer information becomes available and new trends apparent, the City will continue to reevaluate local vulnerabilities.

At the center of this climate change adaptation initiative are two facilitated workshops with City staff. At the first workshop, participants will identify climate change risks and vulnerabilities for each department. At the second, participants will develop robust and integrated strategies for increasing resilience.

Outcomes for the two workshops include:

- a vulnerability assessment relevant to each participating service area
- an organizational assessment to determine how adaptation planning can fit into each department's existing operating procedures
- specific adaptation solutions that are robust across a range of future conditions
- prioritization criteria for adaptation actions

Potential next steps include advancing immediate or future strategies within Departmental planning and implementation processes, as well as incorporation into the forthcoming sustainability strategic plan and climate action plan.

TABLE OF CONTENTS

INTRODUCTION

Purpose: This document was compiled to support climate change adaptation planning for Fort Collins City departments. It includes a review of previous climate change studies, including the *Joint Front Range Climate Change Vulnerability Study*[1] and *Implications of Climate Change for Adatation by Wastewater and Stormwater Agencies*[2]. Supplemental information was obtained from the published literature and new model output related to the IPCC Fifth Assessment Report (AR5)[3], supplemented by AR4 output[4] where AR5 was not available.

Background: Larimer County, located along the Front Range in Colorado, is host to a wealth of natural resources, a vibrant economy, and a leading university. Two major watersheds – the Cache La Poudre and Colorado-Big Thompson – provide water resources for aquatic ecosystems, residents, agriculture, and recreation. Larimer County's population is growing rapidly as people are attracted to the scenery, high quality of life, and rural nature with urban amenities.

Broad scale changes in climate are already impacting local conditions across the West and are likely to continue and accelerate in the coming decades. Changes to local conditions include the timing and availability of water, changes in tree and wildlife species, and changes in wildfire frequency and intensity. Local communities will need to plan for such changes in order to continue to provide vital services to local residents and to support the economy.

Climate change presents us with a serious challenge as we plan for the future. Our current planning strategies at all scales (local, regional, and national) rely on historical data to anticipate future conditions. **Yet due to climate change and its associated impacts, the future is no longer expected to resemble the past.**

MITIGATION – Reducing the amount of greenhouse gases in the atmosphere in order to prevent rapid and irreversible climate change. Irreversible climate change occurs when positive feedbacks kick in to such an extent that emissions reductions are no longer effective.

ADAPTATION – Planning for inevitable impacts of climate change and reducing our vulnerability to those impacts.

This report provides community members and decision-makers in Fort Collins with local climate change projections that can help them make educated long-term planning decisions.

Many of the impacts of climate change are inevitable due to current levels of greenhouse gas emissions already in the atmosphere. Preparing for these impacts to reduce their severity is called "adaptation" (see box). Preventing even more severe impacts by reducing future emissions is called "mitigation." Both are needed.

IS CLIMATE CHANGE A RISK TO FORT COLLINS?

A **risk** is defined as "the possibility of loss or injury." A **risk assessment** involves weighing both the **likelihood** that an event will occur and the **cost** that will be incurred should it occur. Many risks, such as terrorist attacks or earthquakes, have relatively low likelihood yet very high potential cost. Actions are often taken to reduce either the probability (by increasing airport security, for example) or the cost (by instituting new building codes to improve safety in the event of an earthquake, for example) or both.

Communities and individuals use risk assessment as a decision making tool on a daily basis. For example, many people schedule grocery shopping based on the probability of running out of certain items and the cost of running out of those items (running out of toilet paper, for example, may warrant a trip to the store while running out of ketchup may not). Many sectors of society, but especially utilities and emergency response, rely heavily on risk assessment for planning and resource allocation.

Scientists are largely in agreement that the likelihood that human-induced climate change is occurring is **very high** (greater than 95% certainty). Yet many people continue to be skeptical about the scientific evidence for climate change and whether it is human caused. Many people believe that the likelihood that climate change is occurring is low or moderate. Even with a low likelihood, however, there can still be a very high risk if the cost is sufficiently high.

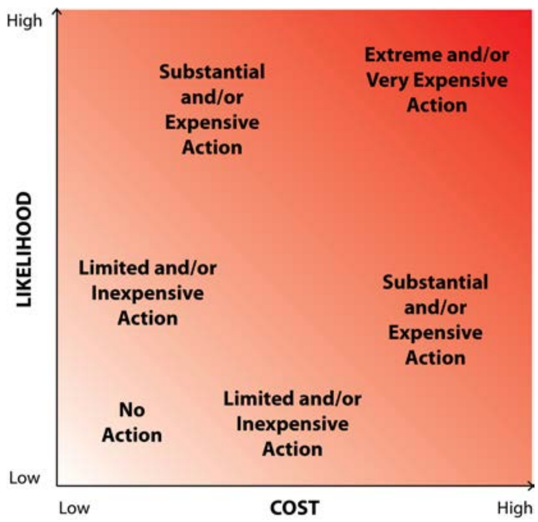


Figure 1. Identifying the level of action warranted based on both the cost and likelihood of an event.

It is important for a community to evaluate the risk of climate change at the local level. This report provides scientific information about how climate change is expected to progress in Fort Collins, Colorado. Using this information, as well as information compiled in a vulnerability assessment for Fort Collins city departments, local leaders, experts, and stakeholders will be tasked with identifying some of the potential costs of changing climatic conditions to the city and its residents.

Participants in this process are not required to overcome their doubts about the science of climate change. Yet they are asked to consider climate change in the same way they consider other risks to the community, by weighing both the likelihood AND the cost, when developing appropriate strategies.

MODELS AND THEIR LIMITATIONS

To determine what conditions we might expect in the future, climatologists created models based on physical, chemical, and biological processes that form the earth's climate system. These models vary in their level of detail and assumptions, making output and future scenarios variable. Differences among models stem from differences in assumptions regarding what variables (and how many) are important to include in models to best represent conditions we care about. Taken as a group, however, climate models present a range of likely future conditions. When we look across the models for areas of agreement, we can assign higher certainty to those specific projections.

The Intergovernmental Panel on Climate Change (IPCC) uses numerous models to make global climate projections.[3] The models are developed by different institutions and countries and have slightly different inputs or assumptions. Specific inputs to these models include such variables as greenhouse gas emissions, air and ocean currents, ice and snow cover, plant growth, particulate matter, and many others.

Most climate models project the future climate at global scales. Managers and decision makers, however, need information about how climate change will impact the local area. Modelers can adjust global model output to local and regional scales using a process called "downscaling." This process increases the precision of the projections, but not the accuracy; they are still associated with high uncertainty and variation.

Model outputs were converted to local scales using local data on historic temperature and precipitation patterns. The climate model output was applied to the vegetation model, which provided data on possible future vegetation types, biomass consumed by wildfire, and carbon storage. Other projections were retrieved from the scientific literature and are based on a variety of different methods specific to each study.

The utility of the model results presented in this report is to help communities picture what the conditions and landscape might look like in the future and the magnitude and direction of change. Some model outputs have greater certainty than others. Information is provided here to explore the types of potential changes, but actual conditions may be quite different, especially if greenhouse gas emissions change substantially.

Uncertainty associated with projections of future conditions, however, should not be used as a reason for delaying action on climate change. The likelihood that future conditions will resemble historic conditions is very low, so **managers and policy makers are encouraged to begin to plan for an era of change, even if the precise trajectory or rate of such change is uncertain.**

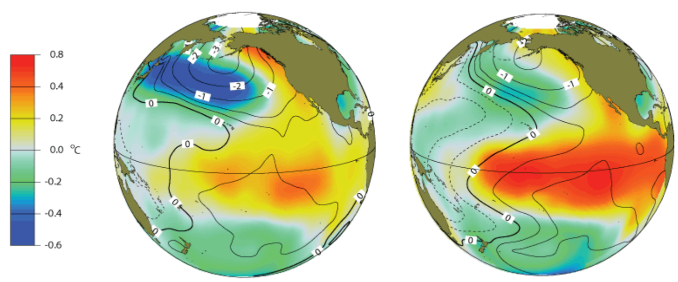
REGIONAL CLIMATE PATTERNS

The climate of the Rocky Mountain region is heavily influenced by the Pacific Decadal Oscillation (PDO). The PDO cycles between a warm phase and a cool phase (Figure 2). Over the last century or more, these cycles have lasted about 20-30 years[4] (Figure 3). Data collected since 1998 (not shown) indicate some potential movement back towards a cool phase of the PDO.[5]

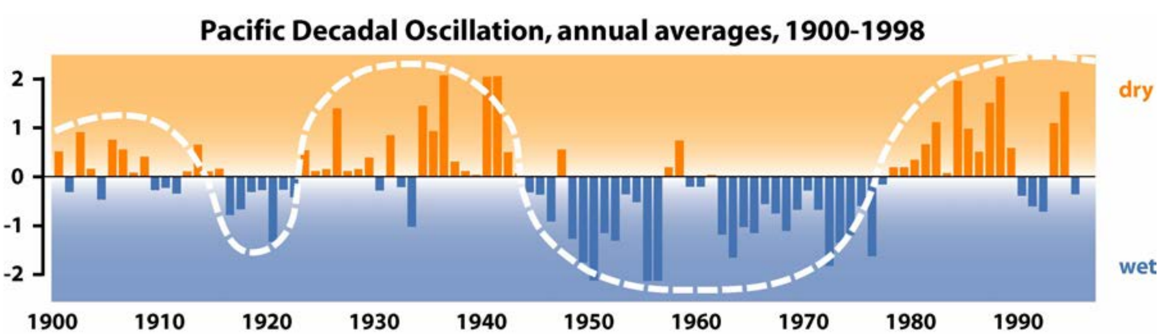
During the warm phase, the surface of the ocean along the coast of North America is unusually warm and low pressure is enhanced over the central North Pacific. This results in warmer than average air temperatures across western North America, especially west of the Rocky Mountains. Some of the characteristics of the warm phase of the PDO, specific to the Front Range in Colorado, are hot dry summers, warmer than average winters, and reduced snowpack. The warm phase of the PDO has been linked to increased wildfire and bark beetle outbreaks.[5]

Embedded within the decades long cycles of the PDO are the one- to two-year cycles known as El Niño-Southern Oscillation (ENSO). When the warm and dry cycle of the PDO coincides with the dry years brought by ENSO, extreme drought and wildfire can occur.

Unfortunately, the precise cause and duration of PDO cycles are not well understood. The PDO was recognized as recently as 1996, and the drivers of the system are still being investigated. While our understanding increases every year, predicting future patterns and, more specifically, the influence of climate change on the PDO are not possible at this time.



Source: Climate Impacts Group, University of Washington



Source: Big Sky Institute, Montana State University

Figures 2 (top) and 3 (bottom). Warm phase PDO (top left) and warm phase ENSO (top right) sea surface temperature anomalies. Lower graph shows a century of Pacific Decadal Oscillation, based on the PDO index.

GLOBAL CLIMATE CHANGE PROJECTIONS

Thousands of independent scientists associated with the International Panel on Climate Change[6] and the U.S. Global Change Research Program[7] agree that the evidence is "unequivocal" that the Earth's atmosphere and oceans are warming, and that this warming is due primarily to human activities including the emission of CO_2, methane, and other greenhouse gases, along with deforestation. Average global temperature has increased by 0.76° C (1.4° F) and is expected to increase by 3.5° - 8° C (6.3° - 14.4° F) within the next century[3] (Figure 4).

The IPCC emission scenario used in this assessment was most often the "business-as-usual" trajectory (A2) that assumes that most nations fail to act to lower emissions. A newer high emissions scenario (RCP8.5) assumes intensive fossil fuels combustion and results in greater change. If the U.S. and other key nations drastically and immediately cut emissions, some of the more severe impacts, like irreversible climate change, may still be avoided.

Due to climate system inertia, restabilization of atmospheric gases will take many decades even with drastic emissions reductions. Reducing emissions (called "mitigation") is vital to prevent the Earth's climate system from reaching certain tipping points that will lead to sudden and irrevocable changes. In addition to emissions reductions, planning for inevitable changes triggered by greenhouse gases already present in the atmosphere (called "adaptation") will allow residents of Fort Collins and the surrounding area to reduce the negative impacts of climate change and, hopefully, maintain their quality-of-life as climate change progresses.

Throughout this report we present mid- and late-century model outputs. **We have more certainty in mid-century projections, due to greenhouse gases already released, but late-century projections may change, depending on future emission levels.**

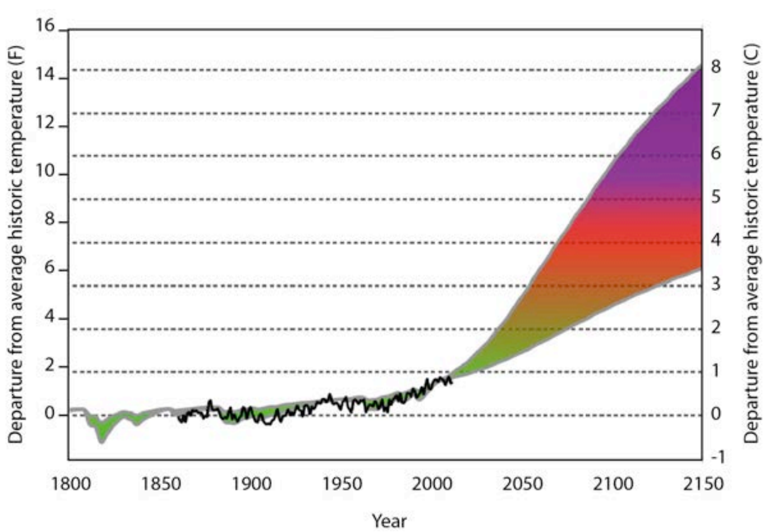


Figure 4. Average global temperatures since 1800, in comparison to projected temperatures through 2150. Data provided by the Environmental Change Institute, University of Oxford. Modeling by Richard Millar consistent with, but not identical to, to the projections of the IPCC.

CLIMATE PROJECTIONS FOR FORT COLLINS AND SURROUNDING REGION

Variables modeled include temperature, precipitation, vegetation type and distribution, wildfire, and carbon storage in biomass. Historical data was analyzed and compared to future projections.

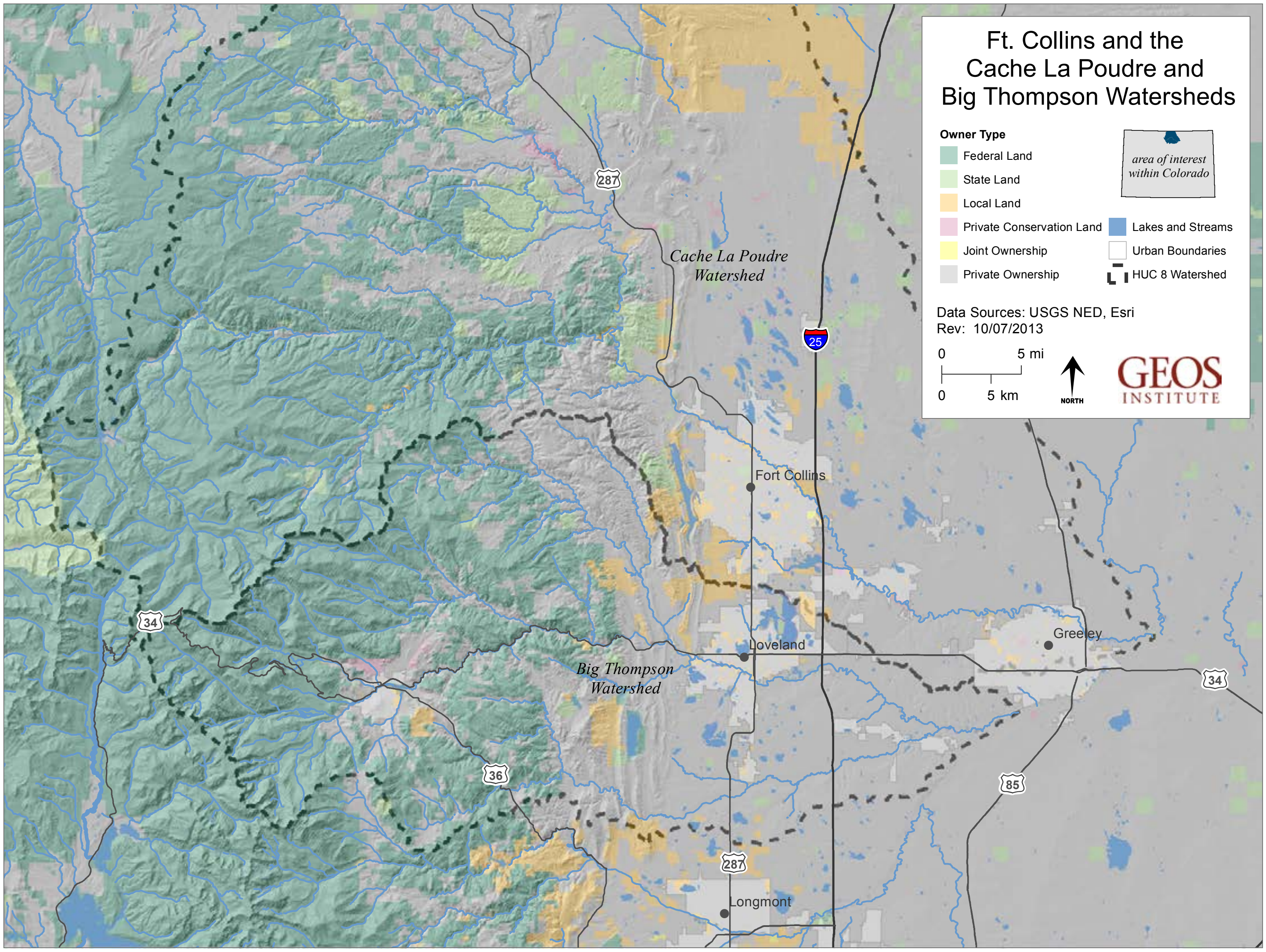
The projections used in this report come from global scale output. When the global model output was adjusted to local scales based on historic variation in temperature and precipitation across the landscape, uncertainty was compounded. Thus, all projections need to be viewed as potential future conditions that are associated with very high uncertainty.

The level of uncertainty is not unlike that associated with forecasting earthquakes, economic trends, population growth, and a whole host of other model projections we rely on for planning purposes.

These projections represent a likely range of possible future conditions in Fort Collins and the surrounding region. As climate change plays out, we may be able to develop more certain projections. We may also experience surprises and unforeseen changes that could not have been projected based on our current understanding.

Climate change projections are provided here in three different formats – as overall averages (seasonal and annual), as graphs that show change over time, and as maps that show variation across the region, but averaged across years. We mapped climate and vegetation variables for the historical period and for two future periods (mid-century and late-century).

Figure 5. Land ownership across the region, including the watersheds that provision the City of Fort Collins, Cache La Poudre and Colorado-Big Thompson.



TEMPERATURE

The Rocky Mountains have experienced significant increase in average seasonal, annual, minimum, and maximum temperatures over the last century.[8,9] Average annual temperature has increased 2-4°F over the last century.[10,11,12] In fact, average temperatures over the past century have warmed two to three times faster in the Rockies than the global trend. Heat waves have increased three-fold since 1961.[45]

The projections from all five models agree, with high certainty, on continued warming for the Fort Collins area (Fig. 6). On average, summer temperatures are expected to rise more than winter temperatures (Fig. 6). Due to emissions already released, mid-century (2035-45) projections are highly likely to be realized while late-century (2065-75) projections are less certain due to potential changes in emissions or positive feedbacks that could accelerate change.

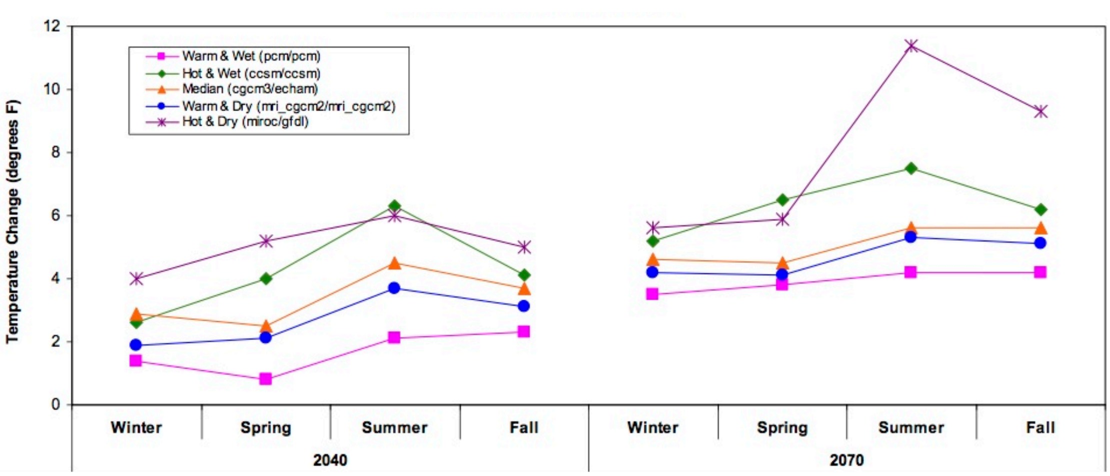


Figure 6. Average temperature change for the Front Range of Colorado, by season, projected for mid-century (left; 2035-45) and late-century (right; 2065-75). From Joint Front Range Climate Change Vulnerability Study 2012. Water Research Foundation.[1]

Figure 7. Average annual temperature across Cache La Poudre and Colorado-Big Thompson Watersheds for the historic period (1961-90) and two future time periods (2035-45 and 2075-85), projected using three different climate models (CSIRO, HadCM, and MIROC) and the A2 emissions scenario.

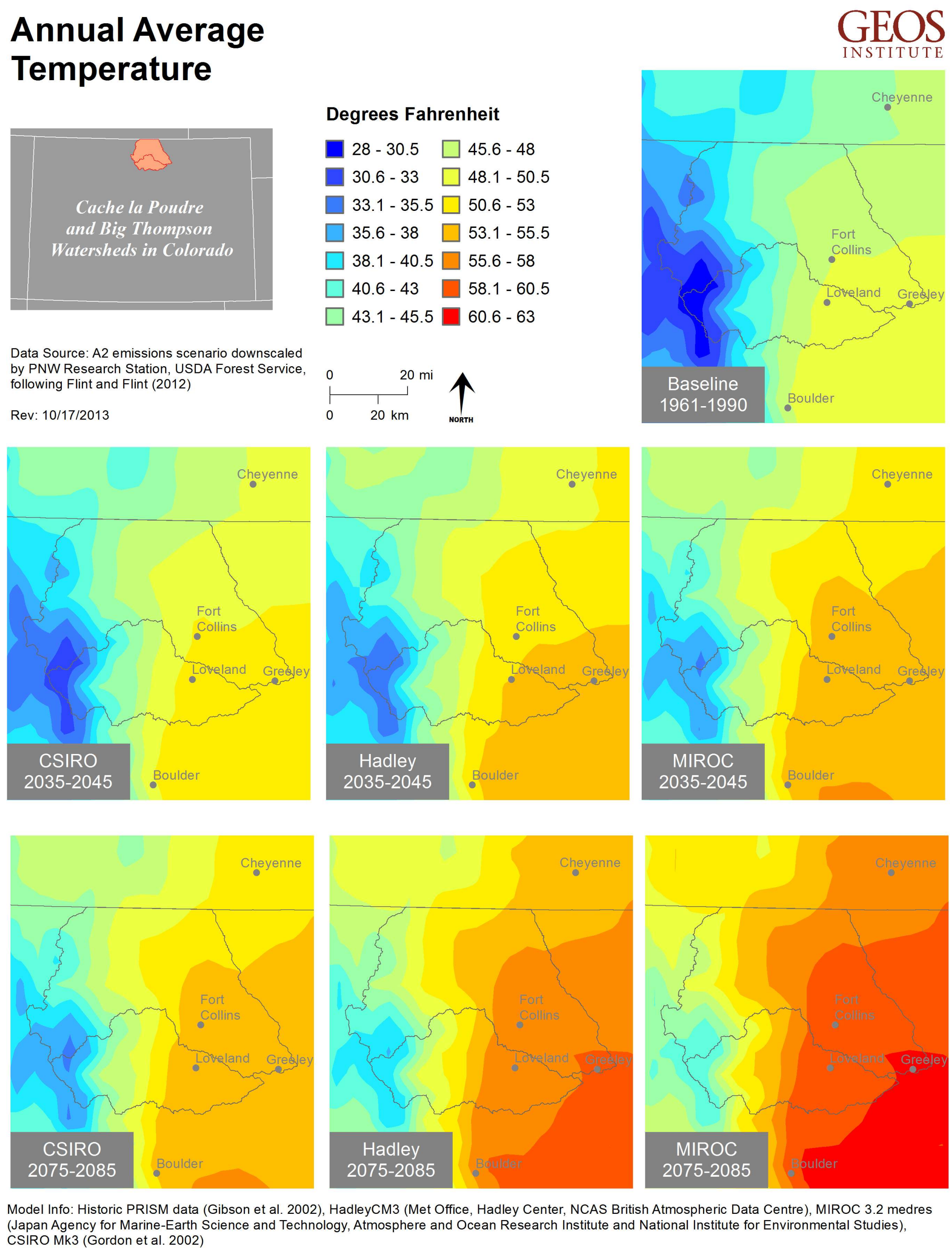


Table 1. Average days per year of especially hot temperatures and heat waves. For the future periods, the values shown are the medians of 60 projections. The percentages in parentheses are comparisons to 1961–1999 averages.[45]

Hot Days and Heat Waves per Year in Fort Collins Observations and Projections						
	Observations		Lower Emissions		Medium-High Emissions	
	1961–1999	2000–2013	2045–2064	2081-2100	2045–2064	2081-2100
Single Days						
90° or hotter	17.9	33.7 (188%)	36.9 (206%)	43.7 (246%)	48.9 (275%)	75.5 (425%)
95° or hotter	2.9	8.8 (309%)	8.8 (309%)	10.7 (375%)	15.2 (533%)	36.7 (1,288%)
100° or hotter	0.1	0.6 (743%)	0.9 (1,125%)	1.3 (1,625%)	1.2 (1,500%)	7.7 (9,625%)
3 Straight Days						
90° or hotter	4.3	12.1 (279%)	15.8 (365%)	20.9 (483%)	22.5 (520%)	51.3 (1,185%)
95° or hotter	0.3	0.9 (290%)	2.0 (645%)	2.6 (839%)	4.2 (1,355%)	23.5 (7,581%)
100° or hotter	0	0 (N/A)	0.2 (N/A)	0.2 (N/A)	0.2 (N/A)	3.2 (N/A)

PRECIPITATION

Over the last century, modest increases in precipitation have been documented for the northwestern United States.[13]

Projections for future precipitation varied among the 5 scenarios (Fig. 10). All five models indicated a trend towards wetter winters, at least through mid-century. Longer and more intense drought might be expected due to potentially drier summers and increased evaporation due to higher air temperature. Even with increased precipitation in the winter, overall drier conditions are expected to develop due to increases in temperature and evaporation.

Currently, the western portion of the two watersheds is considered a snow dominated system, because most precipitation falls as snow. Projections show this system shifting over time to a system that is increasingly rain dominated.

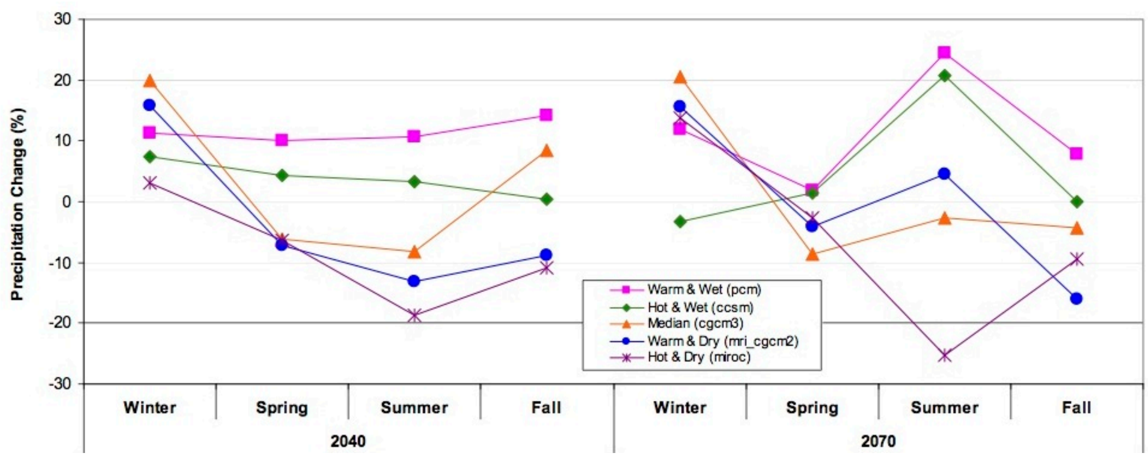
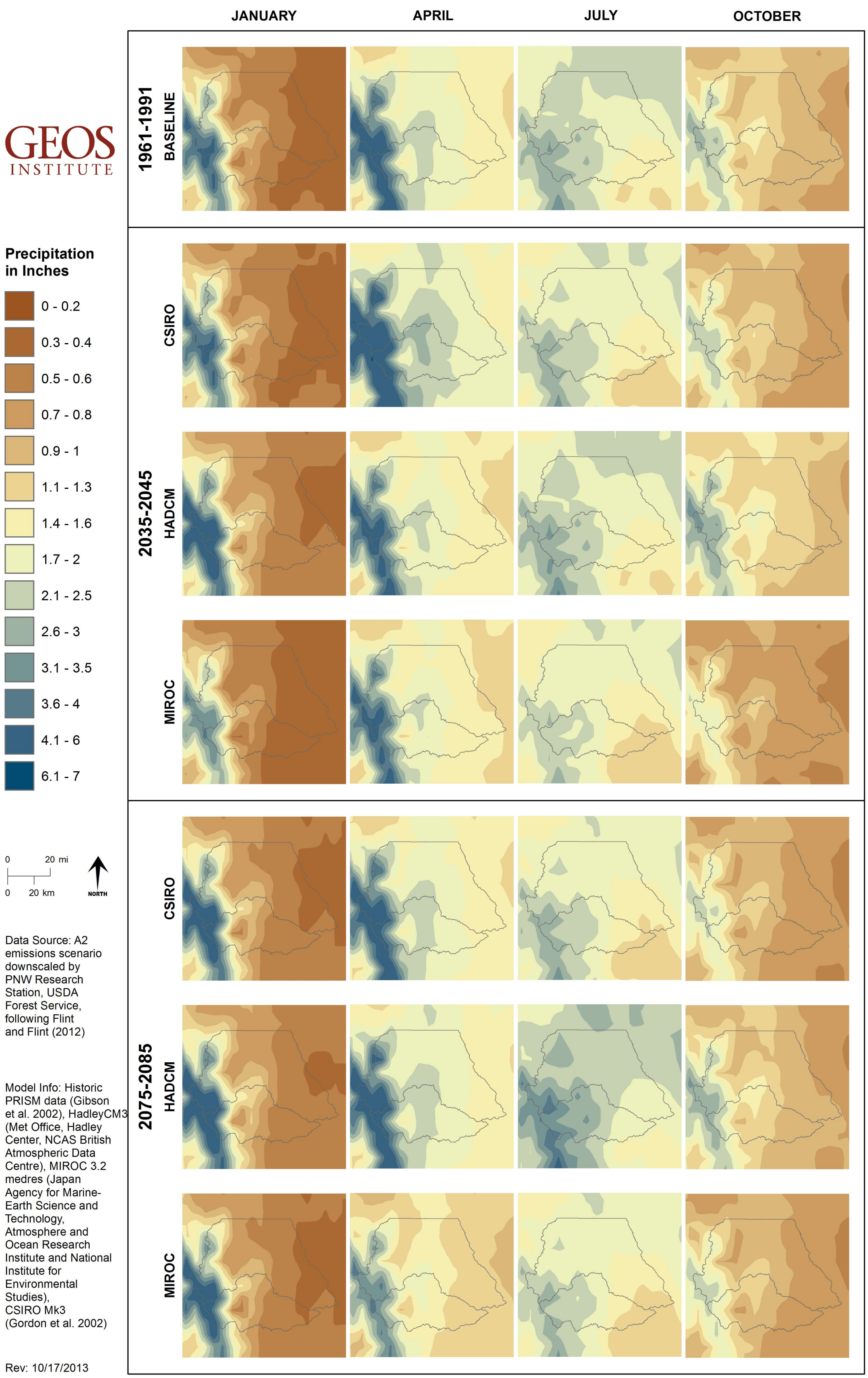


Figure 8. Average seasonal percent change in precipitation for the Front Range of Colorado, projected for mid-century (left; 2035-45) and late-century (right; 2065-75). From Joint Front Range Climate Change Vulnerability Study 2012. Water Research Foundation.[1]

Figure 9 (next page). Average seasonal precipitation across Cache La Poudre and Colorado-Big Thompson Watersheds for the historic period (1961-90) and two future time periods (2035-45 and 2075-85), projected using three different climate models (CSIRO, HadCM, and MIROC) and the A2 emissions scenario.



JANUARY
APRIL
JULY
OCTOBER
1961-1991
BASELINE
2035-2045
CSIRO
HADCM
MIROC
2075-2085
CSIRO
HADCM
MIROC
GEOS
INSTITUTE
Precipitation
in Inches
0 - 0.2
0.3 - 0.4
0.5 - 0.6
0.7 - 0.8
0.9 - 1
1.1 - 1.3
1.4 - 1.6
1.7 - 2
2.1 - 2.5
2.6 - 3
3.1 - 3.5
3.6 - 4
4.1 - 6
6.1 - 7
0 20 mi
0 20 km
NORTH
Data Source: A2 emissions scenario downscaled by PNW Research Station, USDA Forest Service, following Flint and Flint (2012)
Model Info: Historic PRISM data (Gibson et al. 2002), HadleyCM3 (Met Office, Hadley Center, NCAS British Atmospheric Data Centre), MIROC 3.2 medres (Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute and National Institute for Environmental Studies), CSIRO Mk3 (Gordon et al. 2002)
Rev: 10/17/2013

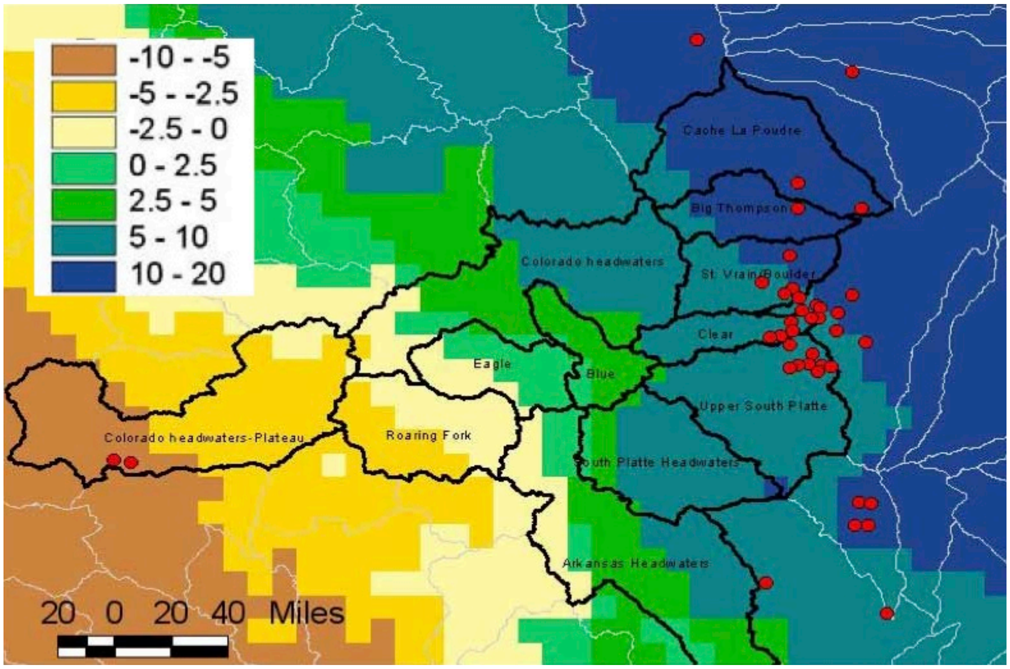


Figure 10. Percent change in total annual average precipitation between the historical period (1950-2000) and the 2070 period (2055-2084) based on the ccsm model. From Joint Front Range Climate Change Vulnerability Study 2012. Water Research Foundation.[1]

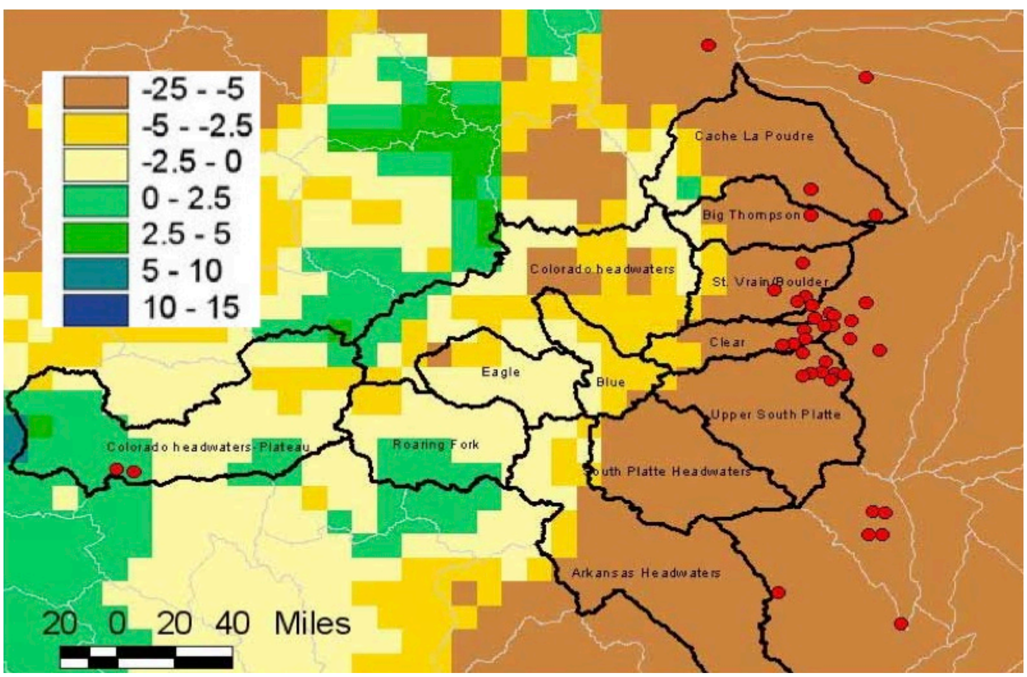


Figure 11. Percent change in total annual average precipitation between the historical period (1950-2000) and the 2070 period (2055-2084) based on the MIROC model. From Joint Front Range Climate Change Vulnerability Study 2012. Water Research Foundation.[1]

SNOWPACK

Rising temperatures throughout the West have led to an increasing proportion of precipitation falling as rain rather than snow[13] and a decrease in spring snowpack at most locations[9,12,14,15]

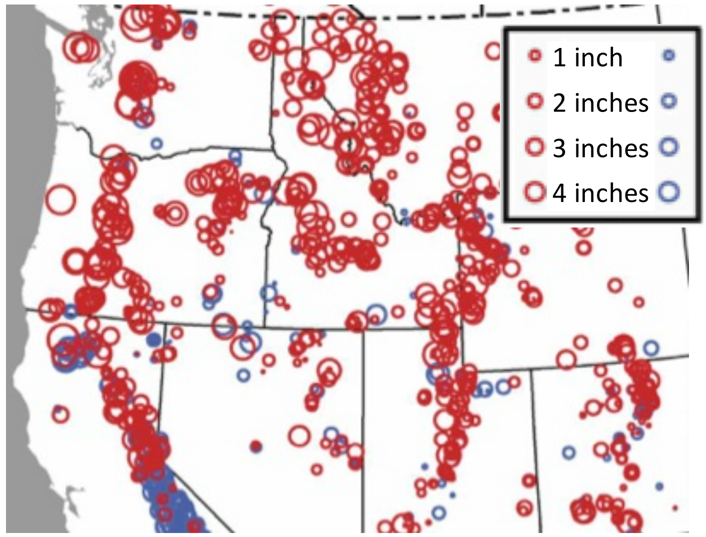


Figure 12. Increases (in blue) and decreases (in red) in April 1st snow-water equivalent (SWE) over the 1960–2002 period of record, adapted from Mote.[12]

In addition to a declining amount of spring snowpack, the moisture content of the spring snowpack – that is the snow-water equivalent or SWE – has declined across the West since the mid-20th century (Figure 14). In the Rockies, this has resulted in a 15.8% decline in SWE.[12] As a result there is less water available to maintain soil moisture and stream flows through the summer months.

As winter minimum temperatures continue to rise in the future, even assuming a conservative estimate of the rate of the likely warming,[16] more western mountains will find themselves in the transient snow zone where snow accumulates and melts repeatedly during the snow season.[12]

Declines in the SWE are expected to continue, affecting snowpack even at higher elevations.[12] Further reductions in spring snowpack and shifts in snowmelt timing can be expected.

HYDROLOGY

Throughout the Rocky Mountains, surface runoff and hydrology is controlled largely by the snow water equivalent (SWE) of winter snowpack.[9]

Many changes to the hydrology of the Western U.S. have been well documented. These include:

Changes in flow

- 15.8% declines in SWE[12]
- Declines in streamflow[14,17,18] Diminished recharge of subsurface aquifers that support summer baseflows[15]
- Summer low flows have declined 29% to 47% during the latter half of the twentieth century[19]

Changes in temperature

- Stream temperatures have increased in many areas[20]
- Increased wildfire leads to even more water temperature increase[21]

Changes in storm intensity

- 16% increase in frequency and intensity of very heavy precipitation[22]
- Increased probability of 20-year flood from 1915 to 2003[23]

Changes in seasonal timing

- Rivers and lakes freeze over, on average, 5.8 days later each century[14]
- Snowmelt and snowmelt-driven runoff also is occurring earlier[24]
- Spring runoff has advanced steadily during the latter half of the twentieth century and now occurs 1 to 3 weeks earlier[18,25]
- Observed streamflow has increased in March and declined in June[18]

A recent report by the Bureau of Reclamation projects that even with a 2% increase in projected precipitation, runoff will decline by 18% and snowpack will decline by 75% in northern Colorado over the next century.[26] Increases in the heaviest downpours are expected to continue during the coming century.[22]

As temperature increase leads to more rain and less snow, the flood risk is expected to increase in the Front Range.[27] Decreases in snow pack and in the length of the snow season could have serious repercussions to winter recreation and water storage alike.

As temperatures and evapotranspiration increase, summer low flows are expected to become more severe, with longer and lower low flows.[27]

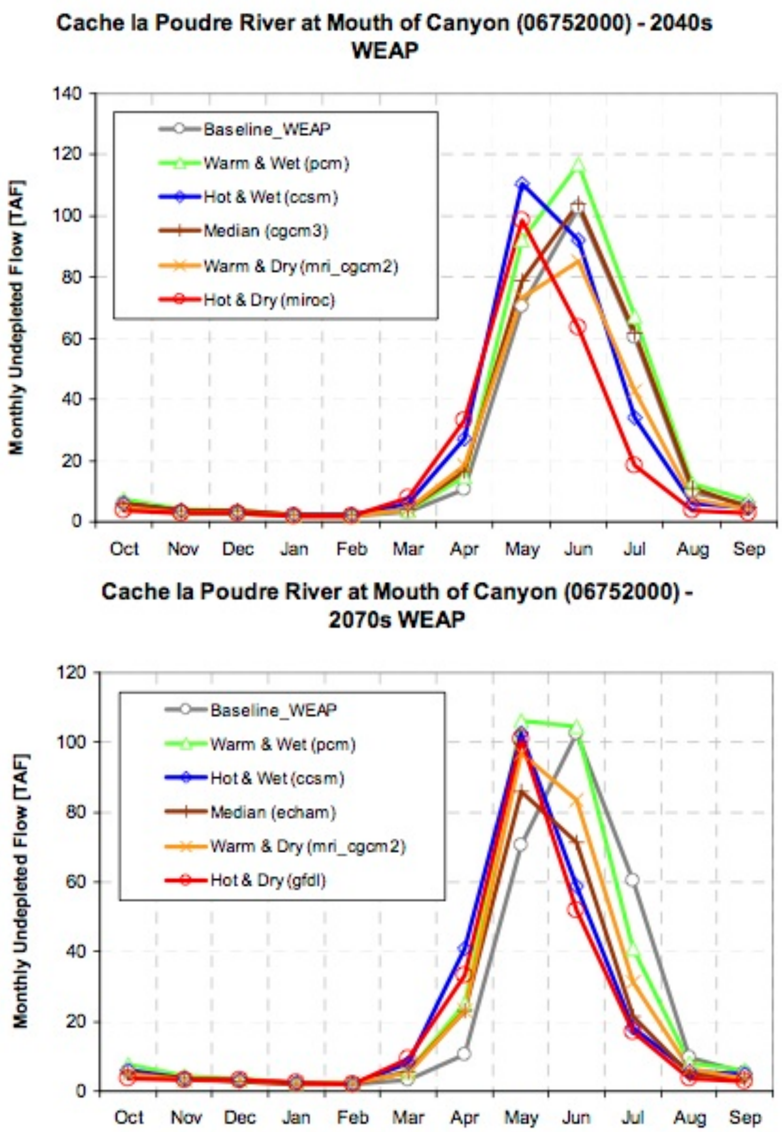


Figure 13. Mid- (top) and late- (bottom) century projections for average monthly stream flow at the Mouth of Canyon, Cache La Poudre River, based on the WEAP model. Projections show earlier spring runoff and potentially lower flows in late summer. From Joint Front Range Climate Change Vulnerability Study 2012. Water Research Foundation.[1]

VEGETATION

Fort Collins is situated on the plains, which are dominated by temperate shrublands and grasslands. The watersheds to the west consist of mid and high elevation forested areas. Forest composition has changed over time. Most changes are due to harvest, natural succession, fire, and insect or disease outbreaks, some of which may be linked to climate change.

Overall, U.S. forests have become more productive in the last 55 years,[28] likely due to a longer growing season and higher CO_2 levels. Treeline has advanced up slope. As conditions become warmer and drier in the summer, forests in some areas are expected to become less productive due to lower soil moisture during the growing season, temperature stress, insect and disease outbreaks, invasive species prevalence, and wildfire.

In this section we present the results from the MC1 dynamic vegetation model,[29] which provides projections for suitable climate for predominant vegetation types rather than individual species.

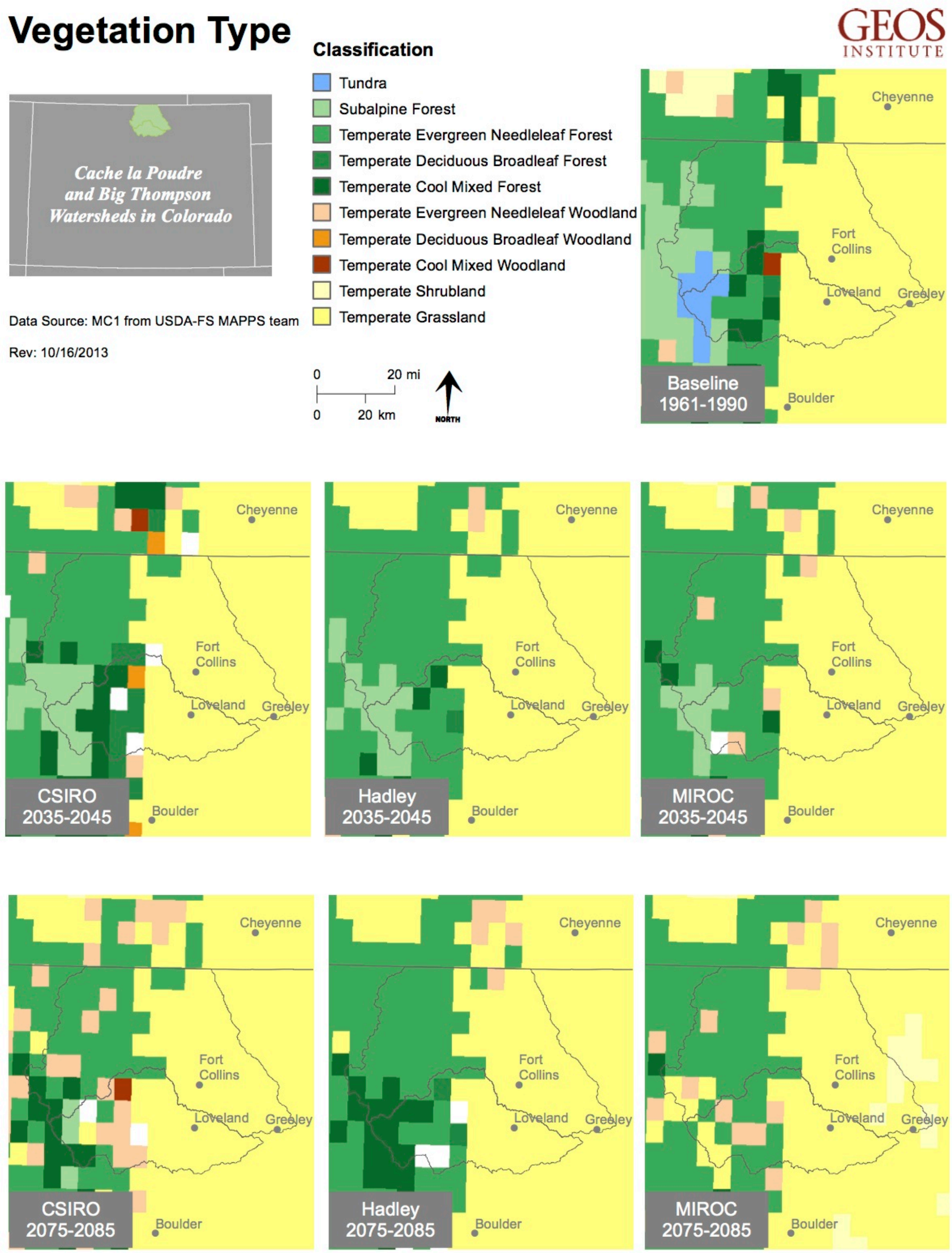
The utility of this model lies in the insight it provides about the potential direction and magnitude of vegetation change that we might see as climate change progresses.

The MC1 vegetation model models only native vegetation and does not account for land use change (i.e. agriculture and development) or introduced species (i.e. non-native grasses). A lag time, which is not considered in the model, is expected between changes in climate conditions and establishment and maturation of new vegetation types on the ground – this lag time could be decades or centuries.

MC1 Vegetation Model Output - For the Fort Collins area, MC1 projects changes in forests, but little change in grasslands (Fig. 14). Subalpine forest is expected to contract while temperate evergreen needleleaf forest is expected to move upslope (Fig. 14).

A newer run of the same model, now called MC2, was completed recently. While not all variables and time slices are available, this model run was based on higher emissions scenarios (RCP8.5) from the IPCC AR5 release. The primary difference in vegetation projections for Fort Collins area is a major shift from temperate grasslands and shrublands to tropical grasslands and shrublands. Results from MC2 are not shown.

Figure 14. Vegetation projections for across Cache La Poudre and Colorado-Big Thompson Watersheds for the historic period (1961-90) and two future time periods (2035-45 and 2075-85), based on output from three different climate models.



WILDFIRE

In the western United States, wildfire is driven by a number of natural factors, including fuel availability, temperature, precipitation, wind, humidity, lightning strikes, and anthropogenic factors, including accidental and intentional fire starts. The natural factors are significantly affected by climate.[30] Wildfire is also closely associated with large scale climate patterns such as El Niño.[28,30]

Wildfire in the West follows a strong seasonal pattern, with 94% of fires and 98% of area burned occurring between May and October.[31] In the Rocky Mountains and Front Range, the fire season is more concentrated toward the later part of the summer, with roughly 50% of annual fire starts occurring in August, the warmest month.[30]

Years with early arrival of spring account for most of the forest wildfires in the western United States (56% of forest wildfires and 72% of area burned, as opposed to 11% of wildfires and 4% of area burned occurring in years with a late spring; Fig. 17).

Wildfire activity increases during warm years, with relatively little activity in cool years. Since the mid-1980s the incidence wildfire, extent of area burned, and length of season all have increased. The frequency of large wildfires in western U.S. forests today is four times greater than it was in 1970-1986.[31] The greatest increase in wildfire frequency has been in the Northern Rockies.[30,31]

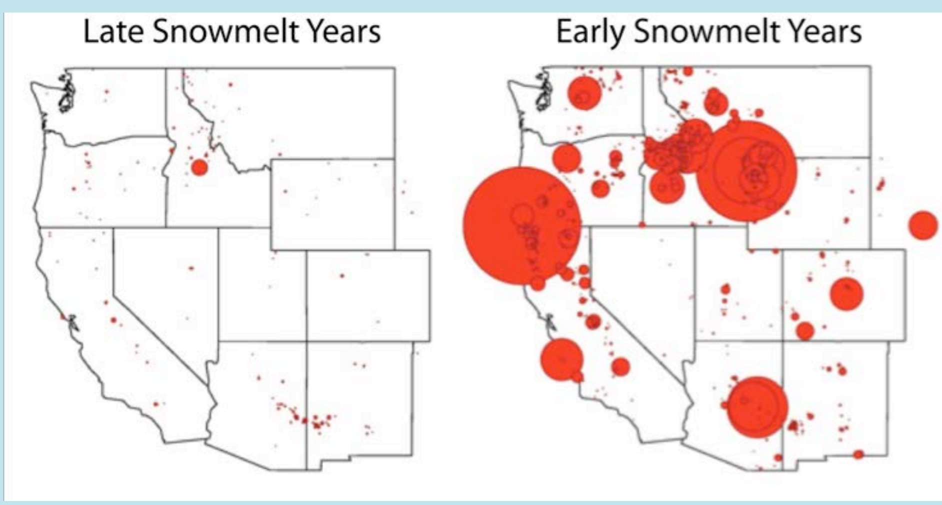


Figure 15. Forest Service, Park Service and Bureau of Indian Affairs large forest wildfires (>1000 acres) for years with early or late spring snowmelt, 1972 - 2003. From *Westerling et al 2006.*[31]

The average length of fire season (the time between the first wildfire discovery date and the last wildfire control date) has increased by 78 days (64%) since 1970. The wildfire season is expanding its reach earlier into spring and later into fall.[30]

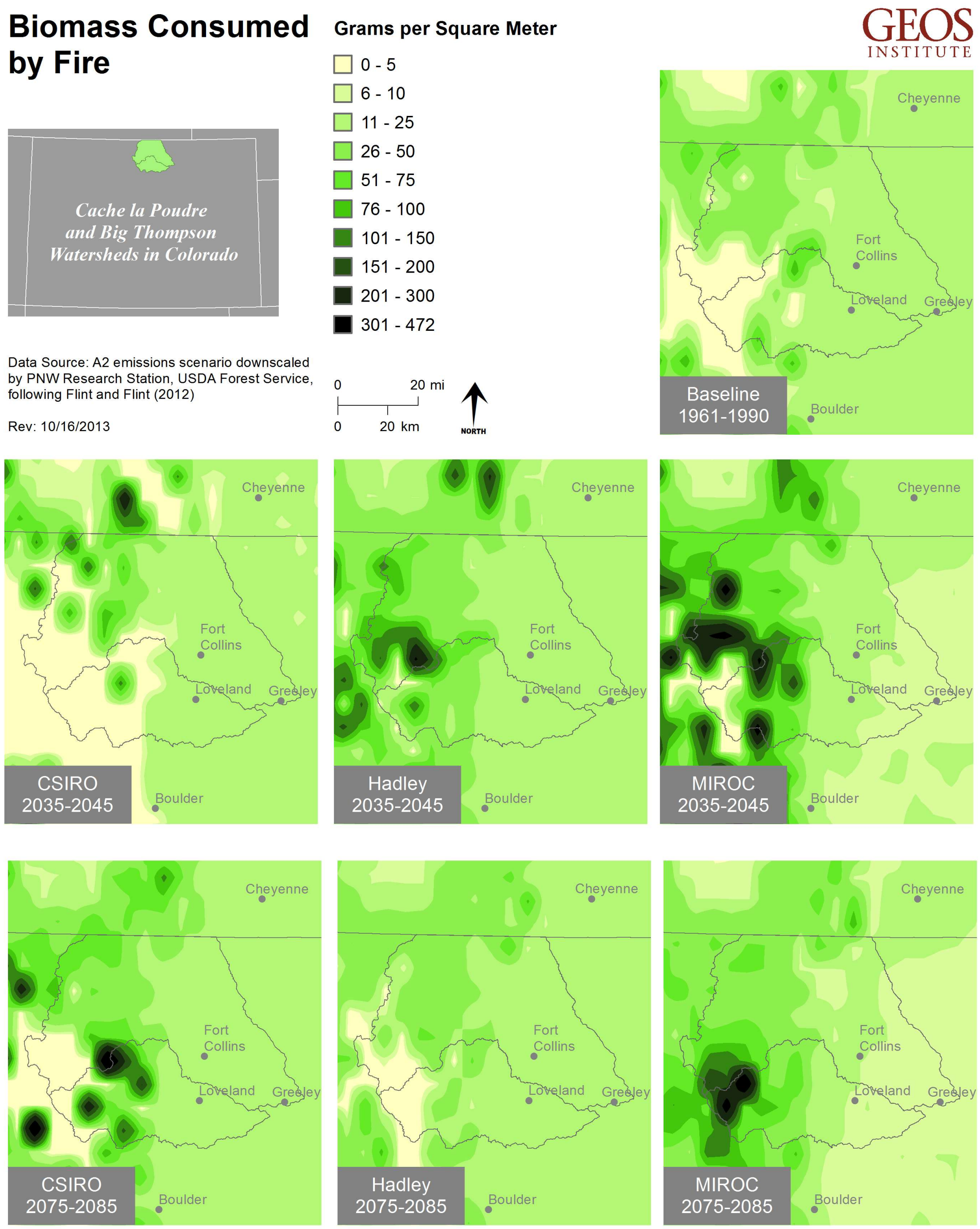
Fire severity can be expected to increase given warmer and drier conditions.[32] An assessment of climate change and forest fires over North America projected 10-50% increases in seasonal severity rating (SSR) over most of the U.S.,[33] implying increases in area burned and fire severity.

Lightning strikes are also expected to increase with increasing CO_2 in the atmosphere[34]. With fire-favorable fuel conditions, increased lightning would yield an increase in the frequency of natural fire occurrence.[35]

Nearly all the western U.S. is projected to experience increases in the number of days with high fire danger by as much as two weeks depending on the region. The areas with the largest changes are the northern Rockies, Great Basin and the Southwest.[32]

The MC1 model projects variable change in wildfire (biomass consumed by fire) over the next century (Figure 18). By mid century, the cooler climate model (CSIRO) reports a decline in wildfire of 45% while the other two (MIROC and HadCM), which project greater warming, suggest an increase of 25-44%. By late century, all three models project an increase in wildfire by 26-30%. Increases in wildfire are primarily projected for the higher elevations.

Figure 16. Average annual biomass consumed by wildfire across Cache La Poudre and Colorado-Big Thompson Watersheds, shown for the historical period (1960-1991) and projected for two future periods (2035-45 and 2075-85), using three global climate models.

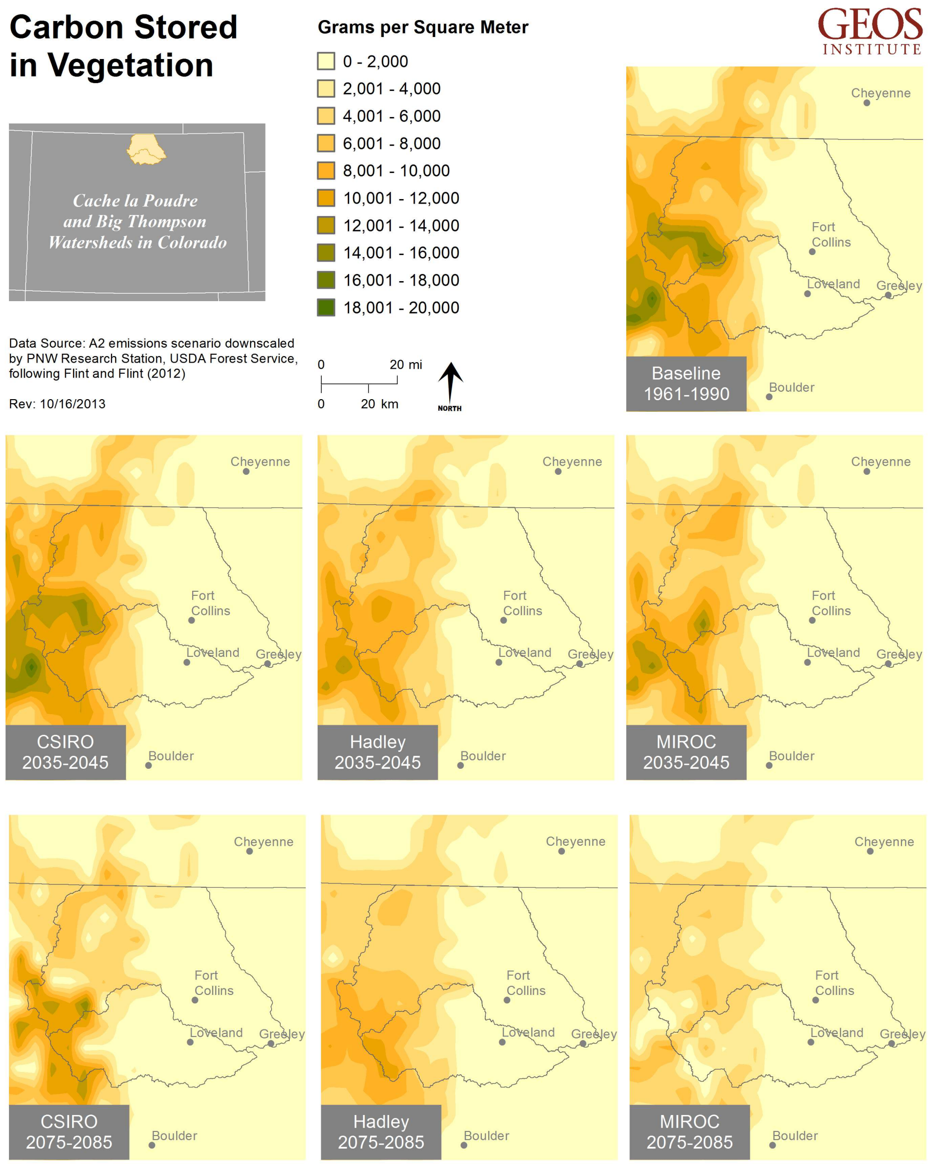


Model Info: Historic PRISM data (Gibson et al. 2002), HadleyCM3 (Met Office, Hadley Center, NCAS British Atmospheric Data Centre), MIROC 3.2 medres (Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute and National Institute for Environmental Studies), CSIRO Mk3 (Gordon et al. 2002)

CARBON STORED IN VEGETATION

All three global climate models indicate a long term decrease in carbon stored in vegetation. Much of the decrease occurs at higher elevations (Fig. 17) where subalpine vegetation is expected to be replaced by temperate evergreen needleleaf forest. As carbon storage in vegetation is reduced, CO_2 is released to the atmosphere, where it will further exacerbate warming and make local emissions goals more difficult to meet.

Figure 17. Average annual carbon storage in vegetation across Cache La Poudre and Colorado-Big Thompson Watersheds, shown for the historical period (1960-1991) and projected for two future periods (2035-45 and 2075-85), using three global climate models.



Model Info: Historic PRISM data (Gibson et al. 2002), HadleyCM3 (Met Office, Hadley Center, NCAS British Atmospheric Data Centre), MIROC 3.2 medres (Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute and National Institute for Environmental Studies), CSIRO Mk3 (Gordon et al. 2002)

ECOLOGICAL CHANGE

Ecological systems of the Fort Collins area are expected to experience substantial change in response to a changing climate. Wetlands, for example, are extremely vulnerable because higher temperatures increase evaporation and cause changes to hydrological systems. As wetlands decline, wetland dependent flora and fauna, such as Western toads and American bitterns, are also expected to decline.[36]

Wildlife is already responding to climate change on a global scale[37] and is expected to continue to respond. Some documented changes include declines in pika,[38] a species found only at high elevations. In contrast, elk in the Rockies have experienced improved conditions due to lower snow pack and warmer winters.[39]

Warmer temperatures, earlier spring, longer dry seasons, more intense storms, and many other factors will increasingly affect wildlife. Wildlife will respond in many ways, including range shifts, changes to migration and breeding seasons, changes in population size, increases in disease, and extinction. As climate change accelerates, it is increasingly expected to outpace the ability of wildlife to respond and adapt.[40] Approximately 30% of all species could be lost.[41]

Some of the wildlife in the Fort Collins area that is expected to be most vulnerable to climate change includes species dependent on snow, such as wolverine, and snowshoe hare.[42] Also vulnerable are high-elevation species such as big horn sheep, pika, marmot, and wolverine, as well as rosy finch and ptarmigan.[42] Many of these species will lose the cool climate and snowy habitat they depend on, and without connections to other areas that are higher and cooler, they are unlikely to migrate to new areas.

Many aquatic species are especially sensitive due to their dependence on cold water streams and their inability to move to new areas. These include cutthroat trout[43]. The boreal toad, which depends on wetlands, marshes, and ponds, may also be affected.

Changing stream flow patterns, increasingly severe storm runoff, and increasing water temperatures will impact aquatic species. Many trout have an especially narrow range of temperature tolerances. In the Rocky Mountains, warming is projected to cause a loss of up to 42% of current trout and salmon habitat by the end of the century.[44]

Invasive species, including noxious weeds, pine and spruce beetles, and others, are expected to continue to spread and to benefit from declining or weakened native species and warmer temperatures, especially in the winter. Warmer waters are also expected to benefit invasive aquatic species and aquatic pathogens.

HUMAN HEALTH IMPACTS

The potential impacts of climate change to human health are substantial. Actual impacts will depend on the level of preparedness at the local level. As communities address the risk of climate change, they should consider local vulnerabilities, including behavior, age, gender, location, and economic status of individuals.

Heat waves – Climate change is expected to lead to more frequent, more severe, and longer heat waves. A recent study of extreme heat in Fort Collins found that historical heat waves (3 or more days of 90° F or higher) occurred 4 times per year, on average. By mid-century, heat waves could occur 23 times per year and by late century 51 times per year.[45]

Extreme weather events – As frequency and intensity of extreme precipitation events increase in some areas, many people will be at risk. In addition to direct effects from flooding and strong winds, such as road closures, damage to infrastructure, injuries, and loss of life, many indirect effects result with extreme weather. These include reduced availability of food and water, interruptions to health care access, power and communications, stomach and intestinal illnesses, and mental health impacts that can last for years after an extreme event.[7]

Air quality – The frequency of days with unhealthy air quality from ground-level ozone are expected to increase with climate change because ozone is formed more quickly at higher temperatures. Ground-level ozone aggravates asthma, causes reduced respiratory function, and is shown to increase the demand for medical services by individuals with lung disease. It also increases the risk of premature mortality and contributes to heart disease risk.[46,47]

Changes in allergens – Spring pollen is occurring earlier with climate change. The length of the allergy season is also increasing. Many plants are expected to produce more pollen due to the increase in CO_2 and temperatures, leading to exacerbated allergy conditions.[7,46]

Climate-sensitive diseases – Diseases that are transmitted through food, water, and wildlife are all expected to increase with climate change. Higher temperatures cause bacteria to grow more quickly in food and water, causing more gastrointestinal disease, which can lead to death in vulnerable populations (infants, elderly, and people with compromised health). Sewage overflow during storms also contribute to contamination of food (crops) and water resources. Water-borne parasites such as *Cryptosporidium* and *Giardia* can increase with heavy rainfall and flooding as well. Finally, Lyme disease and West Nile virus both appear to be extending their range with climate change.[7,48]

CONCLUSIONS

The purpose of this report is to provide up-to-date climate projections for Fort Collins at a scale that can be used in community planning efforts. By providing the information that local managers, decision-makers and community members need to make day-to-day decisions and long-term plans, we hope to spur proactive climate change adaptation planning.

Many of the impacts of climate change are already progressing and will continue to accelerate throughout the next few decades, regardless of future emissions. For instance, projections for mid-century are highly likely to become reality.

Whether we limit climate change to this level or continue to progress towards the level projected for late-century and beyond will depend on whether the U.S. and other key nations choose to lower emissions drastically and immediately.

Our program, called the ClimateWise® program, strives to build co-beneficial planning strategies that are science-based, are developed by local community members, and increase the resilience of both human and natural communities in a cohesive manner.

The strategies developed through this process are robust because they are intended to be effective across the range of uncertainty associated with projections for future conditions. In addition, they are developed locally, and by a diverse group of experts and leaders in the community. Because they are integrated across the sectors, they are likely to reduce future conflict as resources become increasingly limited.

For questions about the information in this report, please contact Marni Koopman at the Geos Institute (marni@geosinstitute.org; 541-482-4459 x303).

LITERATURE CITED

Joint Front Range Climate Change Vulnerability Study[1]

Implications of Climate Change for Adatation by Wastewater and Stormwater Agencies[2].

Working Group I Contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Science Basis Summary for Policymakers". Retrieved 27 September

[4]Randall, D. A., R. A. Wood, S. Bony, et al. 2007. Climate Models and Their Evaluation. *In* Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, et al., Eds. Cambridge University Press.

[4]Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal oscillation with impacts on salmon production. Bulletin of the American Meteorological Society 78:1069-1079.

[5]Mantua, N. 2011. Data available at http://www.jisao.washington.edu/pdo/

[6]IPCC. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

[7]U.S. Global Change Research Program. 2009. Global Climate Change Impacts in the United States. T. R. Karl, J. M. Melillo, and T. C. Peterson, Eds. Cambridge University Press.

[8]Loehman, R. and G. Anderson. 2009. Understanding the science of climate change: Talking points—impacts to western mountains and forests. Natural Resource Report NPS/NRPC/NRR-2009/090. National Park Service, Fort Collins, Colorado, USA.

[9]McWethy, D. B., S. T. Gray, P. E. Higuera, J. S. Littell, G. T. Pederson, A. J. Ray, and C. Whitlock. 2010. Climate and Terrestrial Ecosystem Change in the U.S Rocky Mountains and Upper Columbia Basin: historical and future perspectives for natural resource management. Natural Resource Report NPS/GRYN/NRR—2010/260.

[10]Vose, R. S., D. Wuertz, T. C. Peterson, and P. D. Jones. 2005. An intercomparison of trends in surface air temperature analyses at the global, hemispheric, and grid-box scale. Geophysical Research Letters 32.

[11]Bonfils, C., B. D. Santer, D. W. Pierce, H. G. Hidalgo, G. Bala, T. Das, T. P. Barnett, D. R. Cayan, C. Doutriaux, A. W. Wood, A. Mirin, and T. Nozawa. 2008. Detection and attribution of temperature changes in the mountainous Western United States. Journal of Climate 21:6406-6424.

[12]Mote, P.W. 2006. Climate-driven variability and trends in mountain snowpack in western North America. Amer. Meteor. Soc. 19: 6209-6220.

[13]Knowles, N., M. D. Dettinger, and D. R. Cayan. 2006. Trends in snowfall versus rainfall in the western United States. Journal of Climate 18:4545–4559.

[14]Gray, G., C. Lautenbacher, S. Hays, M.H. Freilich, J. Connaughton, R.E. Foster, M. Myers, L.P. Hirsch, B.K. Ellis, G. Buchanan, L. Lawson, K.L. Olsen, S.H. Wilson, J. Bates, B. Davis, C. McMurray, S.P. Williamson, R.L. Orbach and J. Kupersmith. 2008. Scientific assessment of the effects of global change on the United States. Rept of the Committee on Environment and Natural Resources, National Science and Technology Council.

[15]Hamlet, A.F., P.W. Mote, M.P. Clark, and D.P. Lettenmaier. 2005. Effects of temperature and precipitation variability on snowpack trends in the western United States. J. Climate 18: 4545-4561.

[16] Leung L. R., Y. Qian, X. Bian, W. M. Washington, J. Han, J. O. Roads. 2004. Mid-century ensemble regional climatic change scenarios for the western United States. Climatic Change 62:75–113.

[17]Rood, S.B., J. Pan, K.M. Gill, C.G. Franks, G.M. Samuelson, and A. Shepherd. 2008. Declining summer flows of Rocky Mountain rivers: changing seasonal hydrology and probably impacts on floodplain forests. Journal of Hydrology. 349: 397-410.

[18]Stewart, I.T., D.R. Cayan, and M.D. Dettinger. 2005. Changes towards earlier streamflow timing across western North America. J. Climate 18: 1136-1155.

[19]Luce, C.H. and Z.A. Holden. 2009. Declining annual streamflow distributions in the Pacific Northwest United States. Geophysical Research Letters. 36(L16401).

[20]Kaushel, S. S., G. E. Likens, N. A. Jaworski, M. L. Pace, A. M. Sides, D. Seekell, et al. 2010. Rising stream and river temperatures in the United States. Fronteirs in Ecology and the Environment 8:461-466.

[21]Isaak, D. J., C. Luce, B. E. Rieman, D. Nagel, E. Peterson, D. Horan, S. Parkes, and G. Chandler. 2010. Effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network. Ecological Applications 20:1350-1371.

[22]Karl, T.R., J.M. Melillo, T.C.Peterson, and S.J. Hassol. 2009 Global climate change impacts in the United States. Cambridge University Press.

[24]Barnett, T. P., D. W. Pierce, H. G. Hidalgo, C. Bonfils, B. D. Santer, T. Das, G. Bala, A. W. Wood, T. Nozawa, A. A. Mirin, D. R. Cayan, and M. D. Dettinger. 2008. Human-induced changes in the hydrology of the western United States. Science 319:1080–1083.

[25]Regonda, S. K., B. Rajagoplan, M. Clark, and J. Pitlick. 2005. Seasonal cycle shifts in hydroclimatology over the western United States. J. Climate 18: 372-384.

[26]Reclamation, SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water, Report to Congress, 2011

[27]Hamlet, A. F. and D. P. Lettenmaier. 2007. Effects of 20th century warming and climate variability on flood risk in the Western US. Water Resources Research. 43: W06427.

[28]Boisvenue, C. and S. W. Running, 2006. Impacts of climate change on natural forest productivity – evidence since the middle of the 20th century. Global Change Biology. 12:862 - 882.

[29]Bachelet, D., J. M. Lenihan, C. Daly, R. P. Neilson, D. S. Ojima, and W. J. Parton. 2001. MC1: A dynamic vegetation model for estimating the distribution of vegetation and associated carbon, nutrients, and water - a technical documentation. Version 1.0. GTR-508. Portland, OR: U. S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

[30]Westerling, A. 2008. Climate and Wildfire in the Western United States. 25 pp. UC Merced.

[31]Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science 313: 940–943.

[32]Brown, T.J., B.L. Hall, and A.L. Westerling. 2004. The impact of twenty-first century climate change on wildland fire danger in the western United States: an applications perspective. *Climatic Change* **62:** 365–388, 2004.

[33]Flannigan, M. D., B. J. Stocks, and B. M. Wotton. 2000. Climate change and forest fires. Science of the Total Environment, 262, 221-230.

[34]Price, C. and D. Rind. 1994. Possible Implications of Global Climate Change on Global Lightning Distributions and Frequencies. J. Geophys. Res. 99: 10823–10831.

[35]Swetnam T.W., and J.L. Betancourt, 1990: Fire-Southern Oscillation Relations in the Southwestern United States. Science 249: 1017-1020.

[36]Field, C. B., L. D. Mortsch, M. Brklacich, D. L. Forbes, P. Kovacs, J. A. Patz, S. W. Running, and M. J. Scott. 2007. North America: Contribution of Working Group II to the fourth assessment report of the International Panel on Climate Change. Pages 617-652 *in* M.L. Pary, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson. Eds. Climate Change 2007: Impacts, adaptation, and vulnerability. Cambridge University Press.

[37]Parmesan, C. and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37-42.

[38]Moritz, C., J. L. Patton, C. J. Conroy, J. L. Parra, G. C. White, and S. R. Beissinger. 2008. Impact of a century of climate change on small mammal communities in Yosemite National Park, USA. Science 322:261-264.

[39]Creel S. & M. Creel. 2009. Density-dependence and climate effects in Rocky Mountain elk: an application of regression with instrumental variables for population time series with sampling error. Journal of Animal Ecology 78: 1291–1297.

[40]Bradshaw, W. E. and C. M. Holzapfel. 2006. Evolutionary response to rapid climate change. Science 312:1477-1478.

[41]Thomas, C. D.; A. Cameron, R. E. Green, M. Bakkenes, L. J. Beaumont, Y. C. Collingham, B. F. N. Erasmus, M. F. D. Siqueira, A. Grainger, L. Hannah. 2004. Extinction risk from climate change. Nature 427: 145–148.

[42]Ashton, I. W. 2010. Observed and projected ecological response to climate change in the Rocky Mountains and Upper Columbia Basin: A synthesis of current scientific literature. Natural Resource Report NPS/ROMN/NRR—2010/220. National Park Service, Fort Collins, Colorado.

[43]Haak, A. L., J. E. Williams, D. Isaak, A. Todd, C. C. Muhlfeld, J. L. Kershner, R. E. Gresswell, S. W. Hostetler, and H. M. Neville. 2010. The potential influence of changing climate on the persistence of salmonids of the inland West. USGS Open File Report 2010-1236. 74p.

[44]Keleher, C. J. and F. J. Rahel. 1996. Thermal limits to salmonid distributions in the rocky mountain region and potential habitat loss due to global warming: A geogrphic information system (GIS) approach. Transactions of the American Fisheries Society 125:1-13.

[45]Rocky Mountain Climate Organization. DRAFT 2013. Extreme Heat in Fort Collins. Report for City of Fort Collins. 15 pages.

[46]CCSP (2008). 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.

[47]EPA (2010). Our Nation's Air: Status and Trends Through 2008 (PDF). U.S. Environmental Protection Agency. EPA -454/R -09-002.

[48]Confalonieri, U., B. Menne, R. Akhtar, K.L. Ebi, M. Hauengue, R.S. Kovats, B. Revich and A. Woodward (2007). Human health. In: Climate Change 2007: Impacts, Adaptation and Vulnerability . Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, (eds.), Cambridge University Press, Cambridge, United Kingdom.