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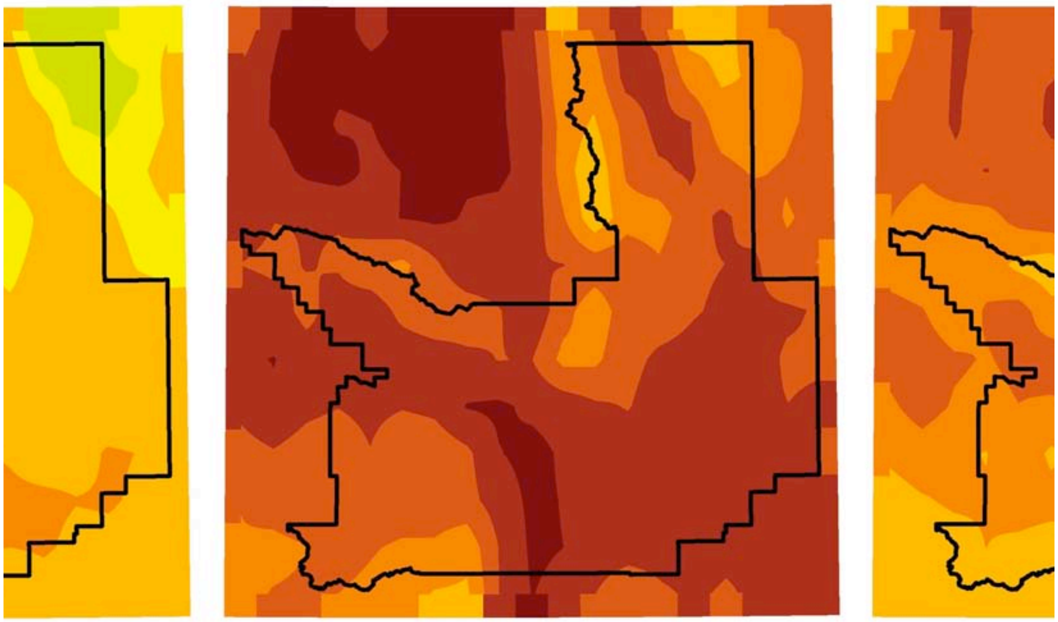
Future Climate Conditions in Missoula County and the Western Montana Region



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Future Climate Conditions in Missoula County and the Western Montana Region

Geos Institute

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EXECUTIVE SUMMARY

Missoula County 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, Missoula County is expected to experience substantial impacts brought on by climate change.

Climate change has already been well documented throughout the Rocky Mountains. Average temperature has 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, 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 Missoula County, we obtained data from global climate models that has been adjusted to local scales. We used three different models to provide us with a range of potential future conditions. Potential changes to the climate and ecology of the region include the following:

High certainty:

- Up to 5° F warmer by 2035-45
- Lower and extended low stream flow in late summer
- Earlier and greater spring runoff
- Shifts in species ranges for wildlife and plants
- Greater likelihood of severe wildfire, especially during warm phase PDO
- Increased spread of invasive plants and animals

Medium certainty:

- Up to 10° F warmer by 2075-85
- Continued declines in snowpack at lower elevations
- Declines in aquatic species such as bull trout and cutthroat trout, as well as amphibians such as the tailed frog
- Declines in alpine and subalpine species, including subalpine fir, Engelmann spruce, big horn sheep, pika, and mountain goat
- Increased impact of pest and disease outbreaks, such as mountain pine beetle

Low certainty:

- Decline in summer precipitation
- Increase in winter precipitation
- Greatest precipitation change at higher elevations
- High tree species turnover, but continued forest cover in many areas
- Declines in Douglas fir and lodgepole pine; potential increase in oaks or other broadleaf tree species.

INTRODUCTION

Missoula County, located along the western border in Montana, is host to a wealth of natural resources, a vibrant economy, and a leading university. Two large rivers – the Blackfoot and the Clark Fork – traverse the county, surrounded by soaring mountains and extensive public lands. Missoula 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 Missoula County with local climate change projections that can help them make educated long-term planning decisions. The climate change model outputs in this report were provided by the USDA Forest Service Pacific Northwest Research Station and mapped by scientists at the Geos Institute. We also provide supplementary information from the scientific literature. This report is intended to precede a community-wide discussion of climate change impacts and local solutions.

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 MISSOULA COUNTY?

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.

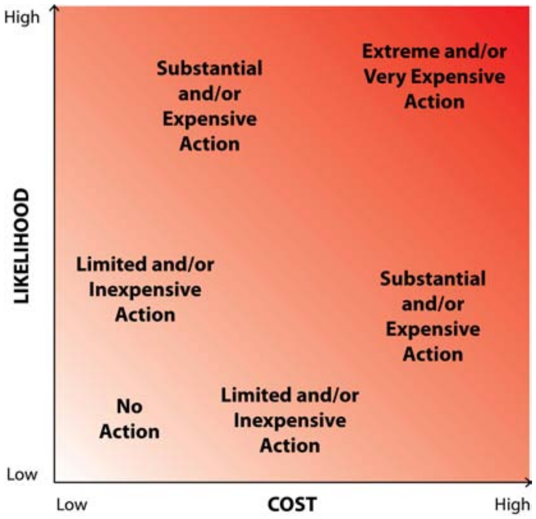


Figure 1. Identifying the level of action warranted based on both the cost and likelihood of an event.

This report is an early step in a process called ClimateWise®. **The ClimateWise® process allows 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 Missoula County. Using this information, as well as information provided in a companion socioeconomic report, local leaders, experts, and stakeholders will be tasked with identifying some of the potential costs of changing climatic conditions that will impact to Missoula County.

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 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.

The Intergovernmental Panel on Climate Change (IPCC) uses numerous models to make global climate projections. The models are developed by different institutions and countries and have slightly different inputs or assumptions. From these models, the MAPSS Team (Mapped Atmosphere-Plant-Soil System) at the USFS Pacific Northwest Research Station chose three global climate models that represent a range of projections for temperature and other climate variables. These three models are Hadley (HadCM, from the UK), MIROC (from Japan), and CSIRO (from Australia). 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.[1] The three models chosen included specific variables, such as water vapor, that were needed in order to run a functional vegetation model called MC1.[2]

HIGH CERTAINTY:

Higher temperatures – Greater concentrations of greenhouse gases trap more heat. Measured warming tracks model projections.

Lower snowpack – Higher temperatures cause a shift from snow to rain at lower elevations and cause earlier snow melt at higher elevations.

Shifting distributions of plants & animals – Many species are limited in extent or number by climatic conditions that are expected to change.

MEDIUM CERTAINTY:

More severe storms – Changes to storm patterns will be regionally variable.

Changes in precipitation – Current models show wide disagreement on precipitation patterns, but the model projections converge in some locations.

Wildfire patterns – The relationship among fire, temperature, and available moisture has been well documented, but other components also play a role (such as vegetation, below).

LOW CERTAINTY:

Changes in vegetation – Vegetation may take decades or centuries to keep pace with changes in climate.

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. The MAPSS Team adjusted global model output to local and regional scales (8km). 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 (see box on previous page). Information is provided her 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.**

Why make changes if the future is uncertain?

Global climate models agree that average temperature will increase. However, projections for other factors such as precipitation or greenhouse gas emissions are highly variable. Why would we invest time and resources into planning for such uncertainty? There are 3 main reasons:

#1 – Planning for continued historic conditions sets us up for failure. Current planning mechanisms use history to plan for the future – such as drought frequency and severity, dam stability, flood risk to communities, etc. Yet no climate models predict continued historic conditions. Relying on continued historical conditions for planning for a community's needs, such as water for residents or snow for recreation, will likely lead to failure.

#2 – We plan for uncertain conditions on a regular basis. Climate change is no different. Some examples include harvesting timber based on models of tree growth and buying fire insurance when we don't expect to have a fire. The potential cost of climate change (by some estimates, around 13% of national GDP by 2040) is so high that we would be prudent to plan proactively and reduce the overall risk.

#3 – Taking action makes the community more resilient and vibrant, regardless of the actual trajectory of climate change. Missoula County is already at risk from catastrophic fire, competition for water, and loss of agricultural and natural lands to development. By addressing these and other issues now, County residents' quality of life is expected to increase.

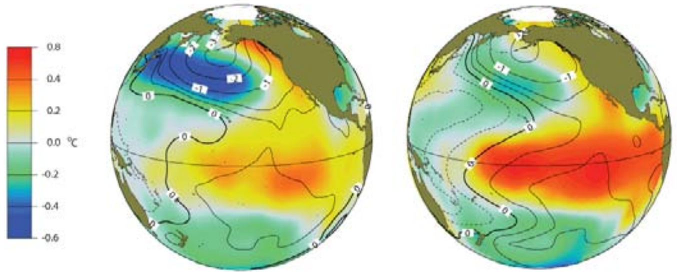
REGIONAL CLIMATE PATTERNS

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[3] (Figure 3). Data collected since 1998 (not shown) indicate some potential movement back towards a cool phase of the PDO.[4]

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 western part of Montana, 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. [4]

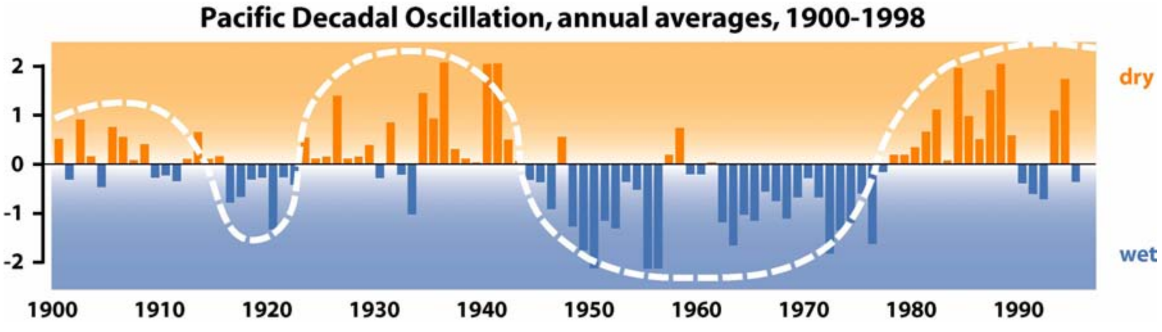
Embedded within the decades long cycles of the PDO are the one- to two-year cycles known as El Niño-Southern Oscillation (ENSO). When the warm and dry cycle of the PDO coincides with the dry years brought by ENSO, extreme drought and wildfire can occur.

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.



Warm Phase PDO Warm Phase ENSO

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[5] and the U.S. Global Change Research Program[6] 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 0.7° C (1.4° F) and is expected to increase by 2° - 6.4° C (3.6° - 11.5° F) within the next century (Figure 4).

The IPCC emission scenario used in this assessment was the “business-as-usual” trajectory (A2) that assumes that most nations fail to act to lower emissions. 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 Missoula County 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.**

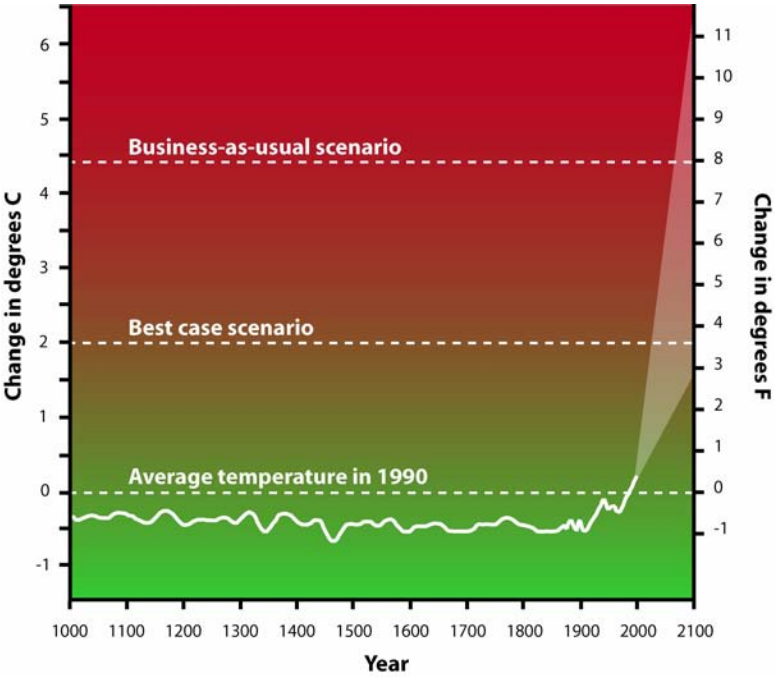


Figure 4. The last 1,000 years in global average temperatures, in comparison to projected temperatures through 2100. Drastic cuts in greenhouse gas emissions (best case scenario) would lead to an increase of about 3.5° F by 2100, while the current trajectory (business-as-usual) will lead to an increase closer to 8° F and as high as 11° F (adapted from IPCC[5]).

The Value of Global Climate Models in Making Local Decisions

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. Due to climate change and its associated impacts, however, the future is no longer expected to resemble the last century, when historical data was collected. To determine what conditions we might expect in the future, climatologists create 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, so each presents a slightly different view of the future. Taken as a group, however, climate models present a range of possible future conditions.

Emissions Scenario

Human activities and their associated greenhouse gas emissions are difficult to predict. Different potential human responses were considered, providing a range of possible "scenarios." Climate projections discussed in this report are based on the "business-as-usual" (A2) greenhouse gas emission scenario.[5] The global emissions path of the late 1990s closely followed this scenario; a sharp rise in emissions since 2000 means that emissions during the past decade exceeded those used in the modeling in this report[7] (see also http://www.realclimate.org/index.php/archives/2010/06/recent-trends-in-co2-emissions/). Consequently, the climate projections indicated in this report may underestimate future trends. A concerted effort to lower emissions could, in contrast, lead to less severe temperature increases than those depicted in this report. Due to emissions already released, mid-century projections are likely to be realized. Late-century projections, on the other hand, are more uncertain die to potential changes in emissions or positive feedbacks.

Climate Models

Scientists at the Geos Institute displayed potential future climate conditions in Missoula County using three global climate models – CSIRO, MIROC, and HadCM (for a thorough discussion of the models, see Randall et al. 2007[1]) under the A2 emissions scenario. Output was converted to the locally-relevant scale of 8km by the USDA Forest Service MAPSS team at the Pacific Northwest Research Station.

Climate models rely on equations describing physical relationships in the atmosphere, land surface, cryosphere (ice and snow), and oceans to project future conditions. The Intergovernmental Panel on Climate Change (the leading scientific organization assessing climate change and the risks to environmental and socioeconomic resources) tested the ability of these three models, and many others, to accurately reflect historical climate patterns and conditions. The MAPSS team selected CSIRO, MIROC, and HadCM from the suite of available models for three primary reasons: (1) because they perform well in the Western U.S.; (2) because they provide a range of projections, from the warmer end of the spectrum to the cooler, and also from wetter to drier; and (3) because they provide outputs that are needed to run the MC1 vegetation model. The MC1 vegetation model provides us with projections for such variables as growing conditions for dominant types of vegetation, wildfire, and carbon storage in biomass.

While model projections will always encompass uncertainty (models are simplified representations of complex processes) they are the best available tools for assessing future conditions, thus allowing us to identify risks, develop adaptation strategies, and build plans based on potential future scenarios. As actual trajectories are revealed and new approaches are developed, plans will need to be revisited and revised in an adaptive management context to reflect new information.

CLIMATE PROJECTIONS FOR MISSOULA COUNTY

Variables modeled using HADCM, CSIRO, MIROC, and the vegetation model (MC1) include temperature, precipitation, vegetation type and distribution, wildfire, and carbon storage in biomass. Historical data was analyzed and compared to future projections.

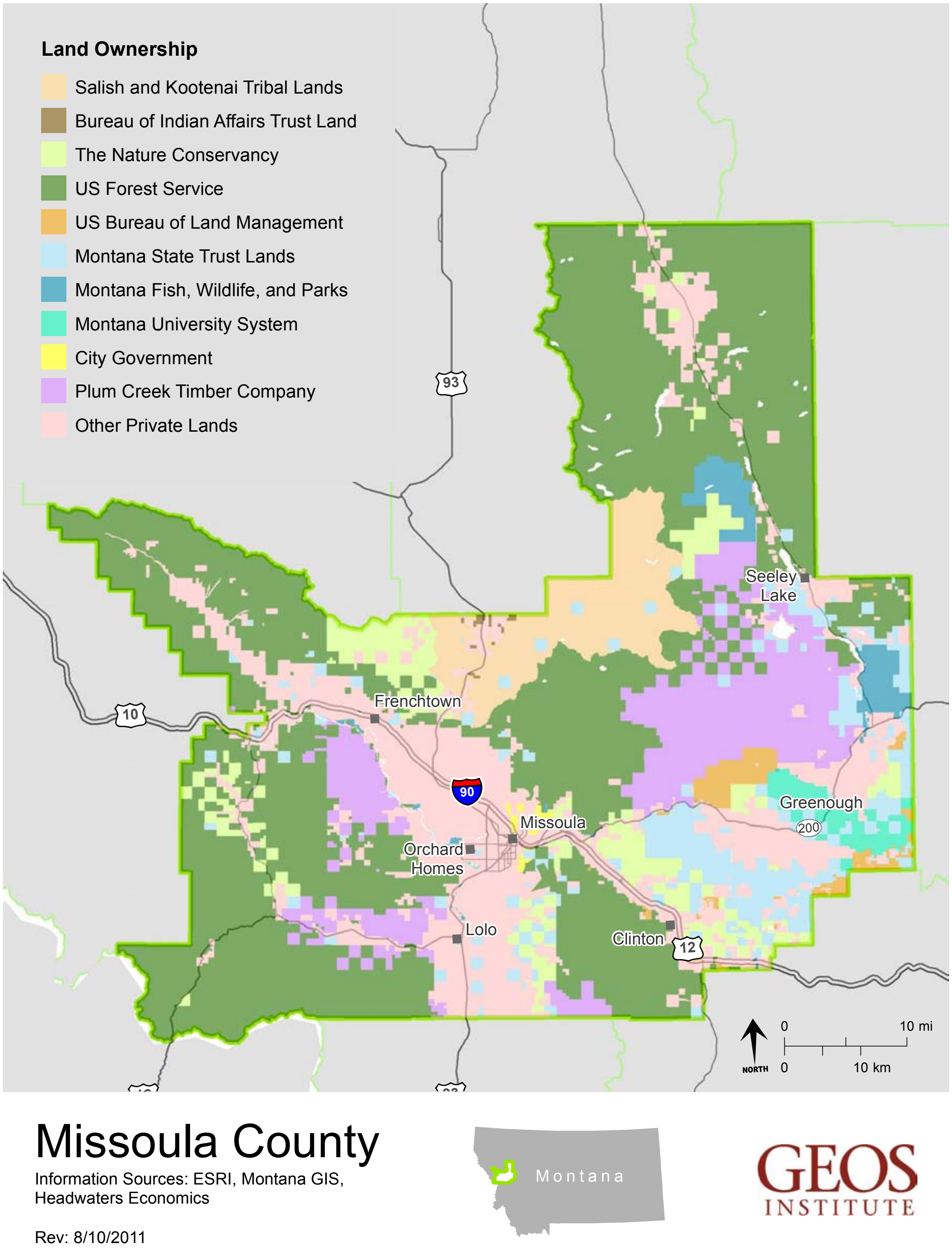
The projections used in this report come from global scale output. When the global model output was adjusted to local scales based on historic variation in temperature and precipitation across the landscape, uncertainty was compounded. Thus, all projections need to be viewed as potential future conditions 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 Missoula County 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, 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 (1961-1990) and for two future periods (2035-45 and 2075-85).

Figure 5. Land ownership in Missoula County.



TEMPERATURE

The northern Rockies 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 northern Rockies of Montana than the global trend.

The projections from all three models agree, with high certainty, on continued warming for Missoula County (Table 1). On average, summer temperatures are expected to rise more than winter temperatures (Fig. 7). Due to emissions already released, mid-century (2035-45) projections are highly likely to be realized while late-century (2075-85) projections are less certain due to potential changes in emissions or positive feedbacks that could accelerate change.

Table 1. Projected increase in average temperature in Missoula County, based on output from three different global climate models. Future projected temperature is shown as change in degrees Fahrenheit, as compared to historic averages (1961-1990).

	Historic	2035-45	2075-85
Annual	40.5° F	+2.5 to 4.8° F	+5.7 to 10.0° F
Summer*	59.2° F	+2.2 to 5.5° F	+6.4 to 11.0° F
Winter**	23.0° F	+2.5 to 5.0° F	+5.1 to 9.3° F

*Summer value was calculated as average temperature for June, July, and August

**Winter value was calculated as average temperature for December, January, and February

Figure 6. Average annual temperature for Missoula County, based on historic data and model projections from three global climate models, assuming the “business as usual” A2 emissions scenario.

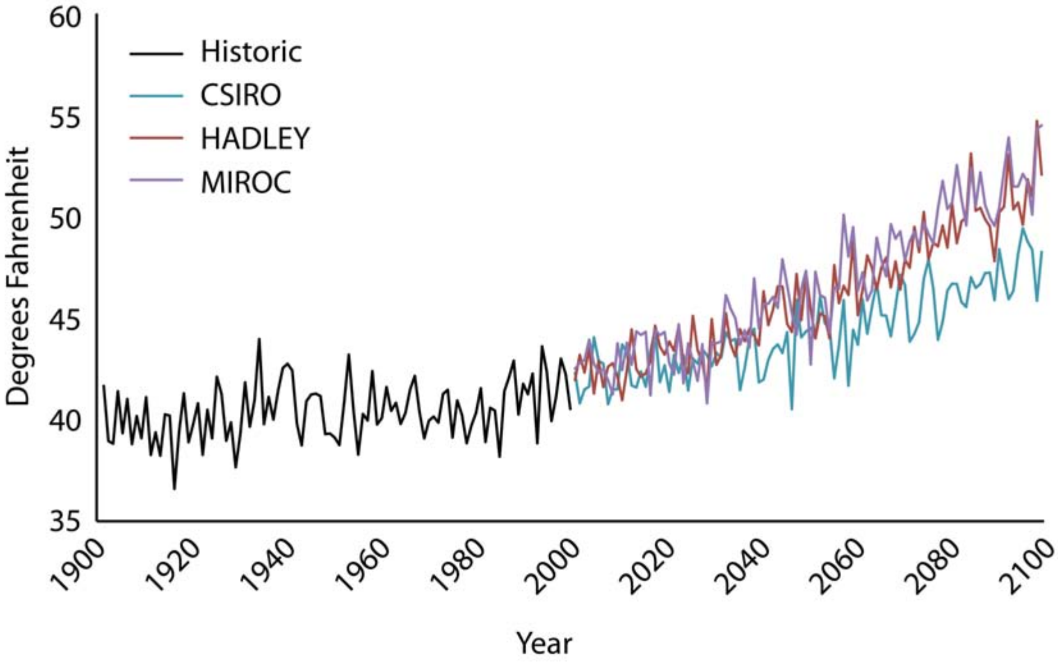


Figure 7. Average historic and future monthly temperatures in Missoula County. Historic average temperature shown in blue. The full range of projected future average temperatures, based on output from three global climate models, is shown in green for mid-century (2035-45) and red for late-century (2075-85).

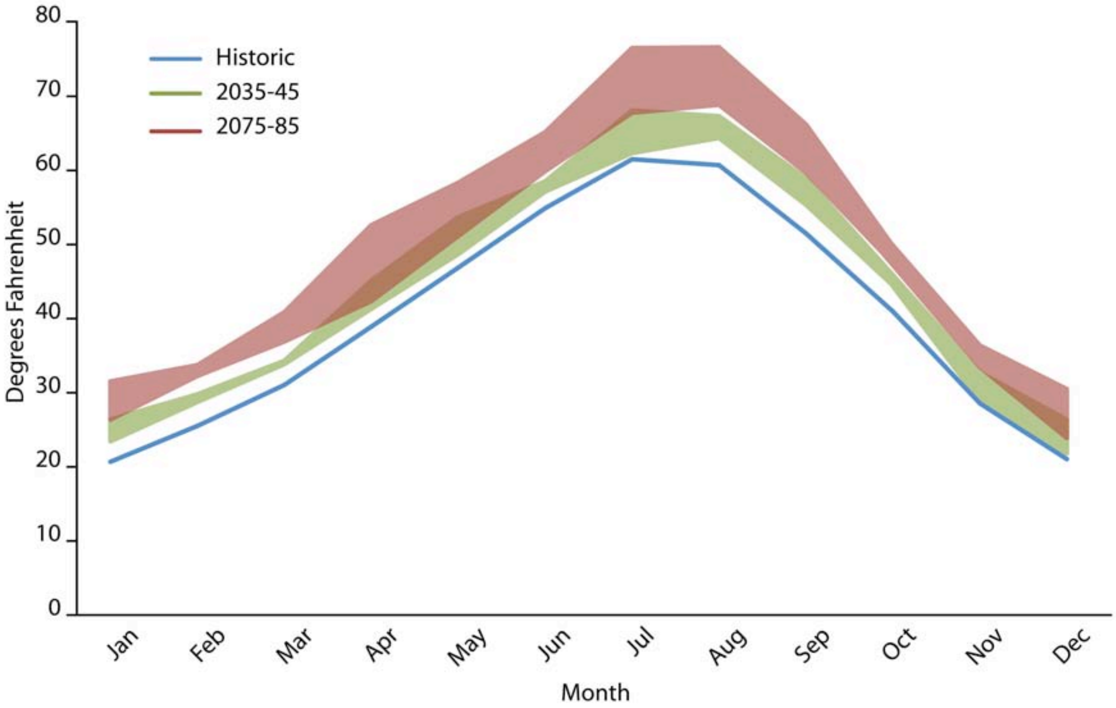


Figure 8. Average monthly temperature across Missoula County for the historic period (1961-90) and two future time periods (2035-45 and 2075-85), projected using three different climate models.

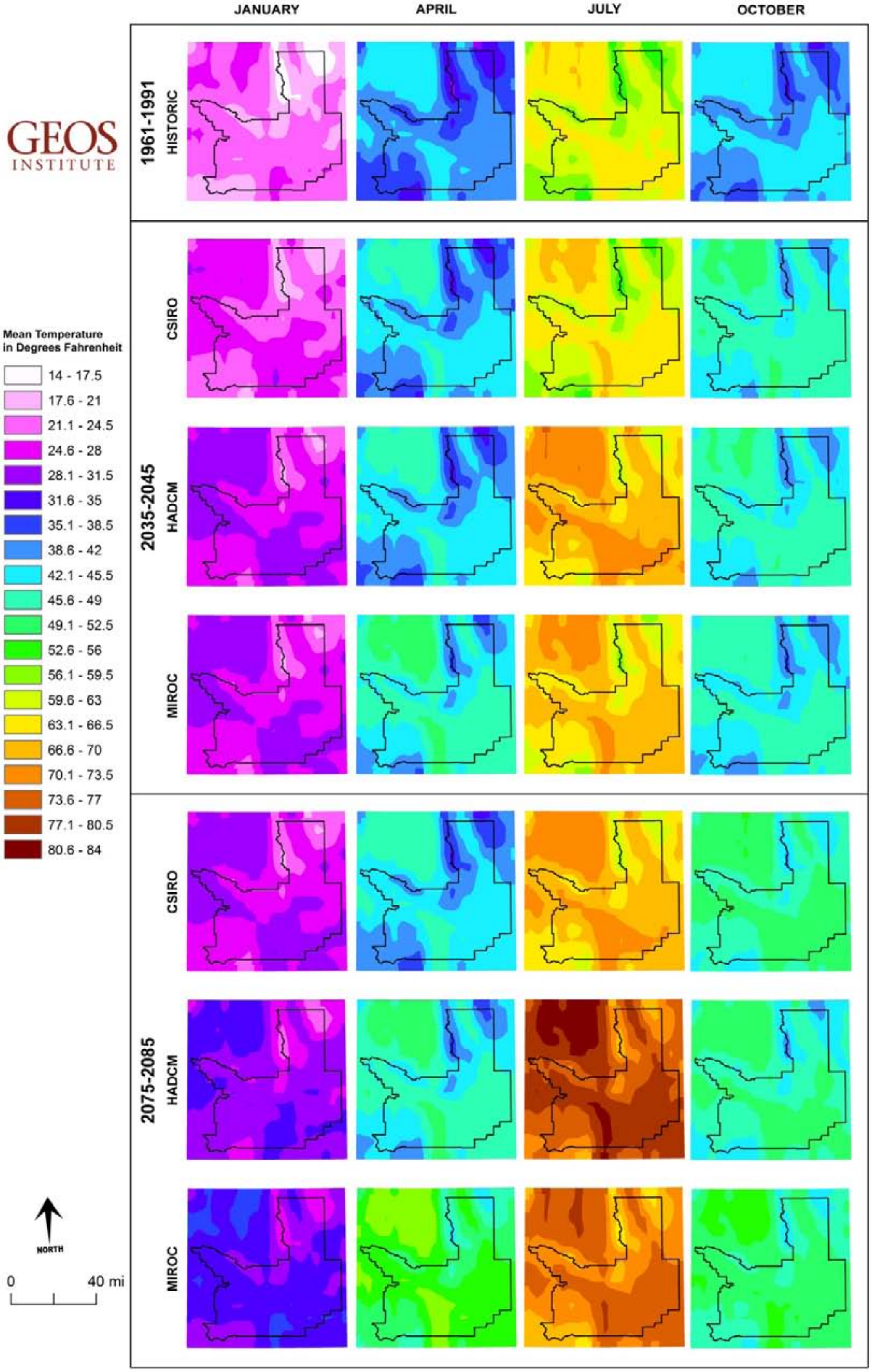
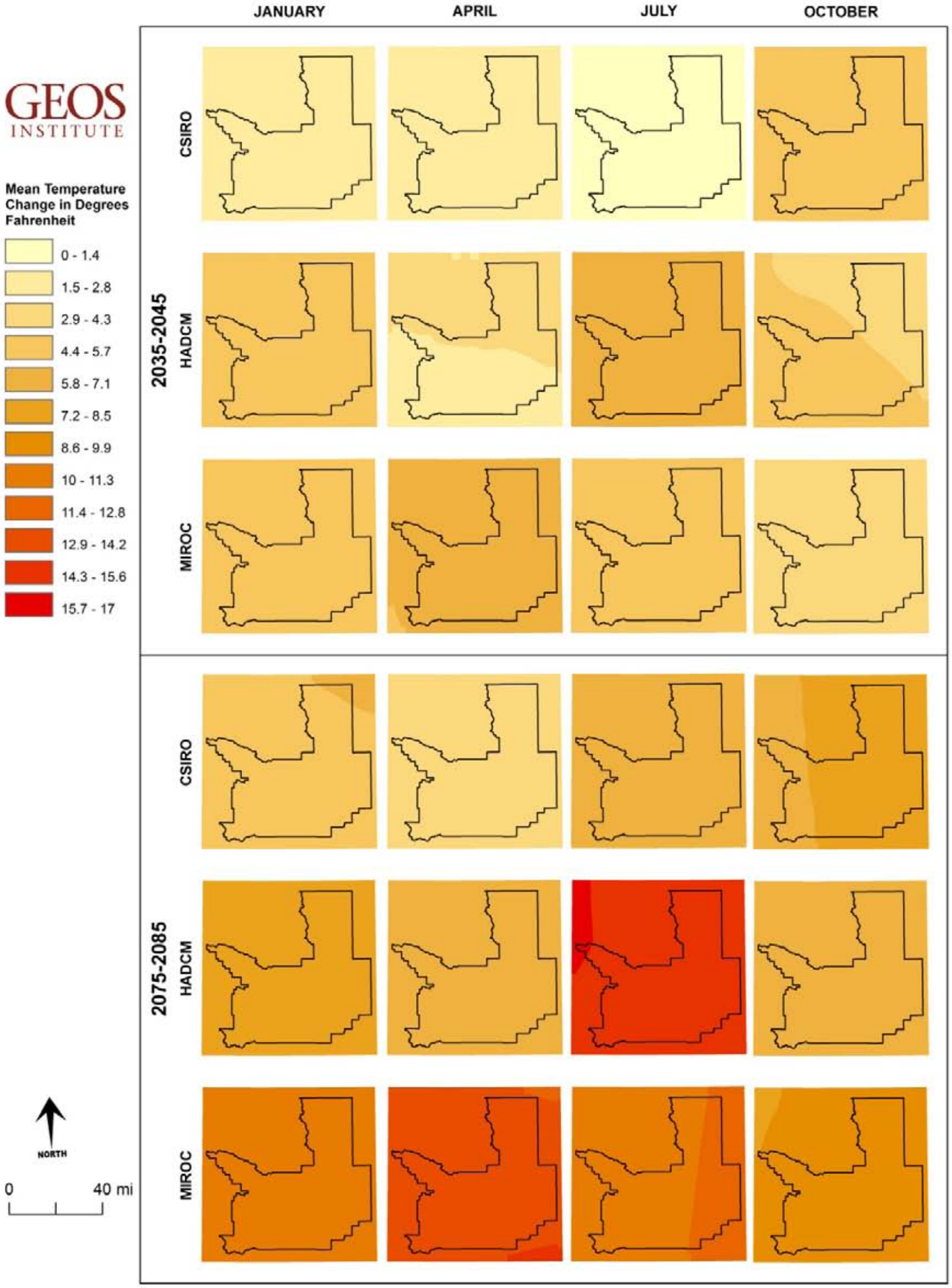


Figure 9. Projected change in average monthly temperatures across Missoula County for mid-century (2035-45) and late-century (2075-85) as compared to historic averages (1961-1990).



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 three models (Fig. 10). All three models indicated a trend towards drier summers and wetter winters (Table 2). Longer and more intense drought might be expected due to 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 eastern portion of Missoula County is considered a snow dominated system, because most precipitation falls as snow. Projections show this system shifting over time to a system that is snow dominated during the coldest months, but increasingly rain dominated at lower elevations and during the spring and fall,[14] which is similar to the middle and western portions of the county today.

Table 2. Projected average precipitation (and percent of historic average) across all of Missoula County (including valleys and mountains), based on output from three different global climate models. Future projected precipitation is shown in inches, as compared to historic averages (1961-1990). Precipitation measurements and projections include both rainfall and snow water equivalent.

	Historic	**2035-45**	**2075-85**
Annual	31.1 inches*	32.1 to 32.6 in. (103-105%)	33.8 to 35.7 in. (109-115%)
Summer**	5.6 inches	4.0 to 6.2 in. (71-110%)	3.5 to 5.6 in. (63-96%)
Winter***	10.5 inches	11.4 to 12.4 in. (108-118%)	12.7 to 14.3 in. (121-137%)

*In contrast, the average precipitation in the city of Missoula is 13.7 inches.
**Summer value was calculated as the sum of precipitation for June, July, and August
***Winter value was calculated as the sum of precipitation for December, January, and February

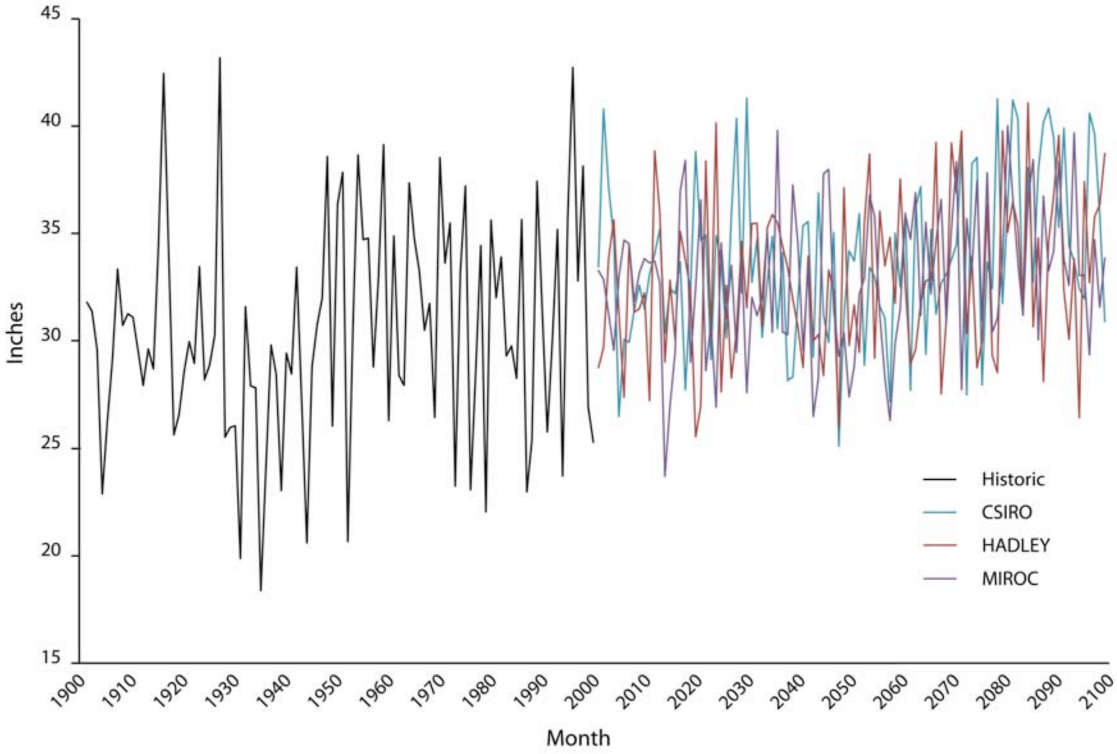


Figure 10. Average annual precipitation across Missoula County, based on historical data (black line) and three global climate models projected out to 2100. Precipitation measurements and projections include both rainfall and snow water equivalent.

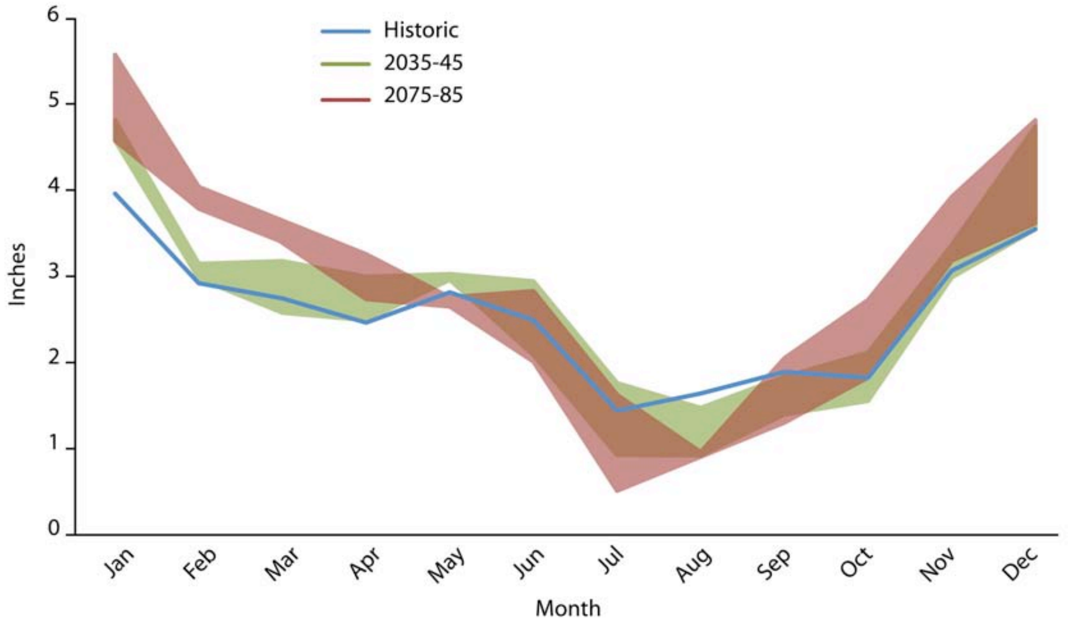


Figure 11. Average monthly historic (1961-1990) precipitation is shown in blue. The full range of projections from three global climate models for average precipitation in Missoula County is shown for two different time periods – 2035-45 in green and 2075-85 in red. Precipitation projections include both rainfall and snow water equivalent.

Figure 12. Average monthly precipitation across Missoula County for the historic period (1961-90) and two future time periods (2035-45 and 2075-85), projected using three different climate models.

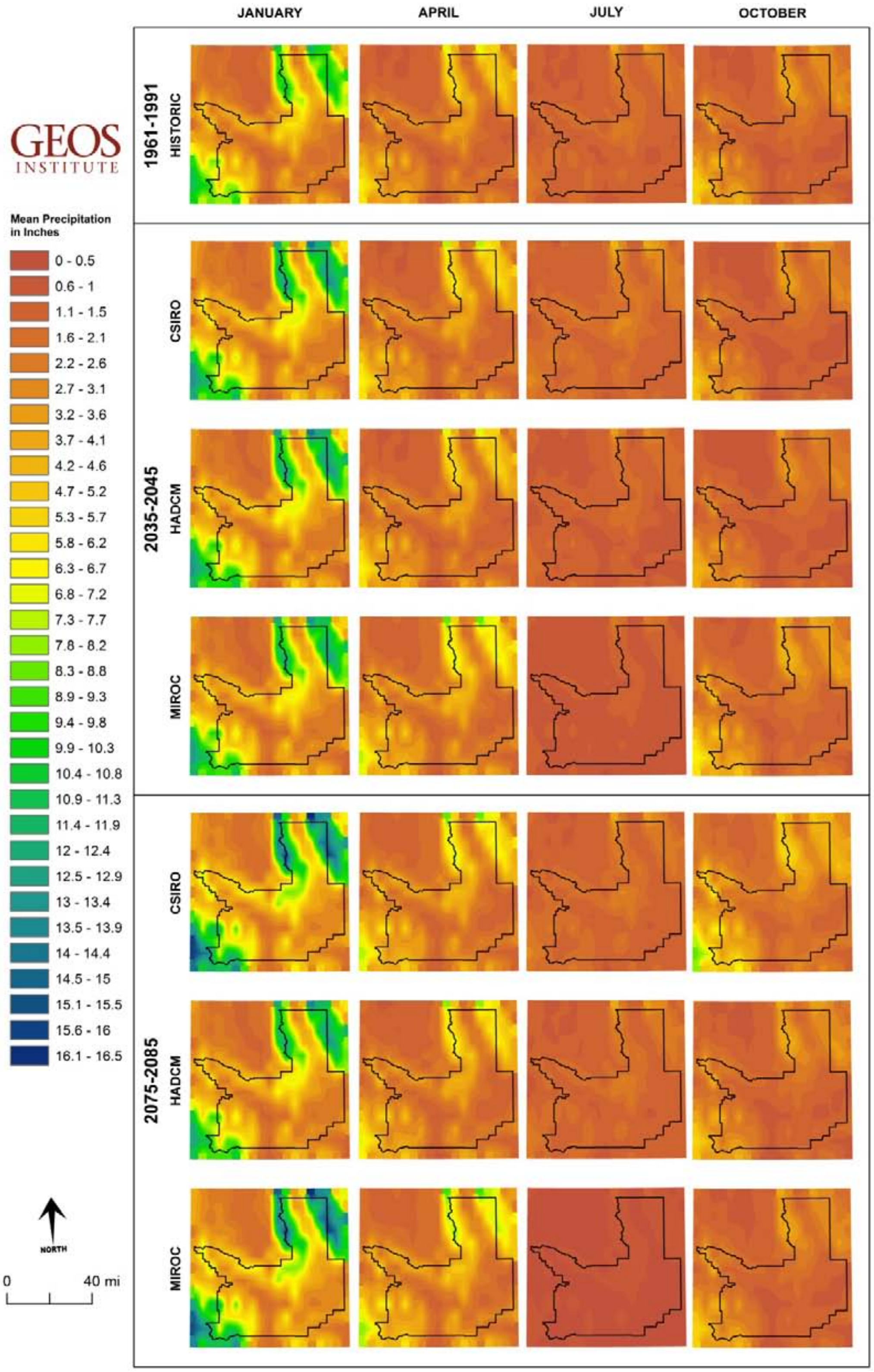
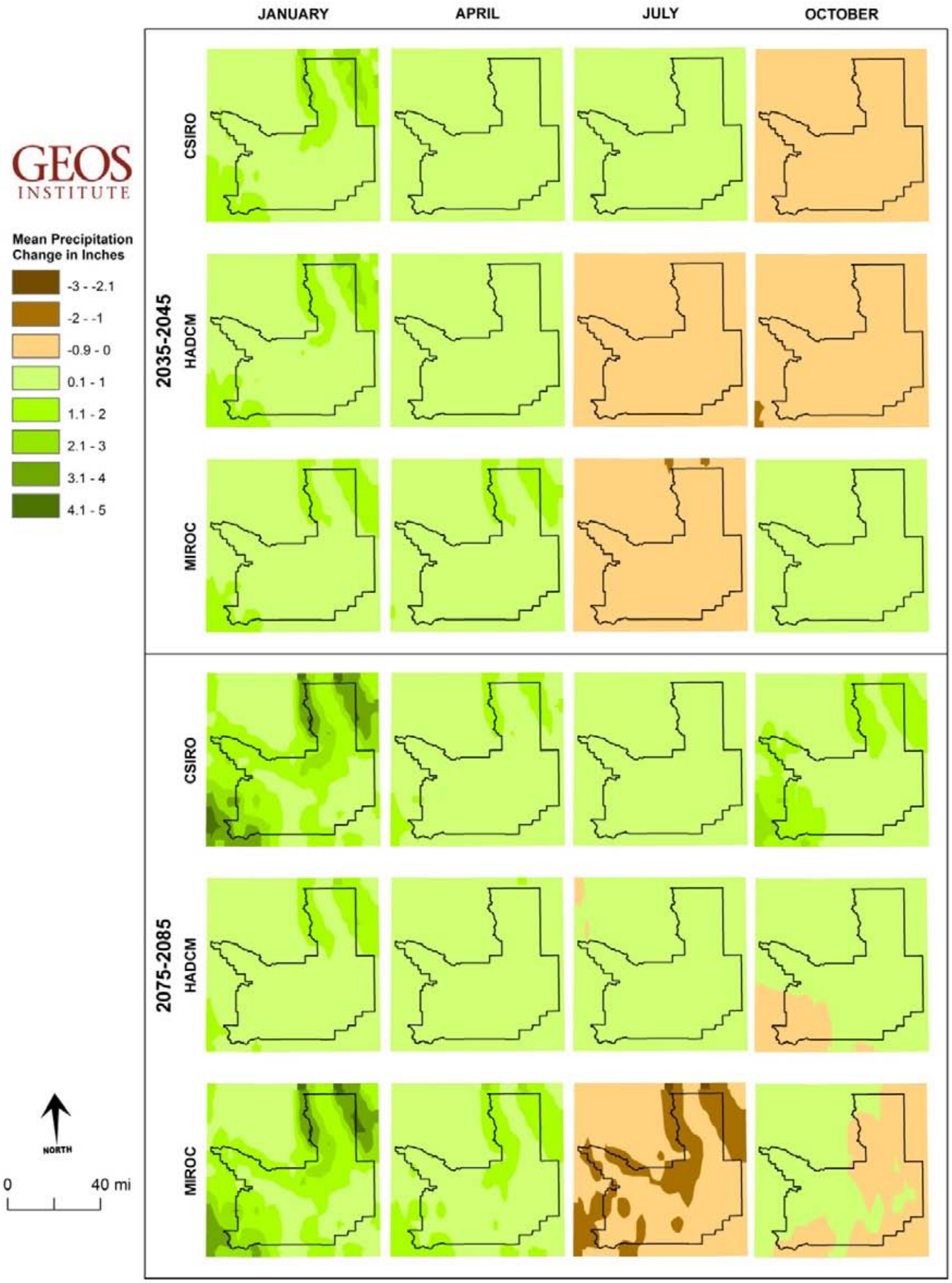


Figure 13. Average monthly change in precipitation across Missoula County for two future time periods, 2035-45 and 2075-85, as compared to historic averages (1961-1990).



SNOWPACK

Rising temperatures throughout the West have led to an increasing proportion of precipitation falling as rain rather than snow[15] and a decrease in spring snowpack at most locations[9,12,16,17]

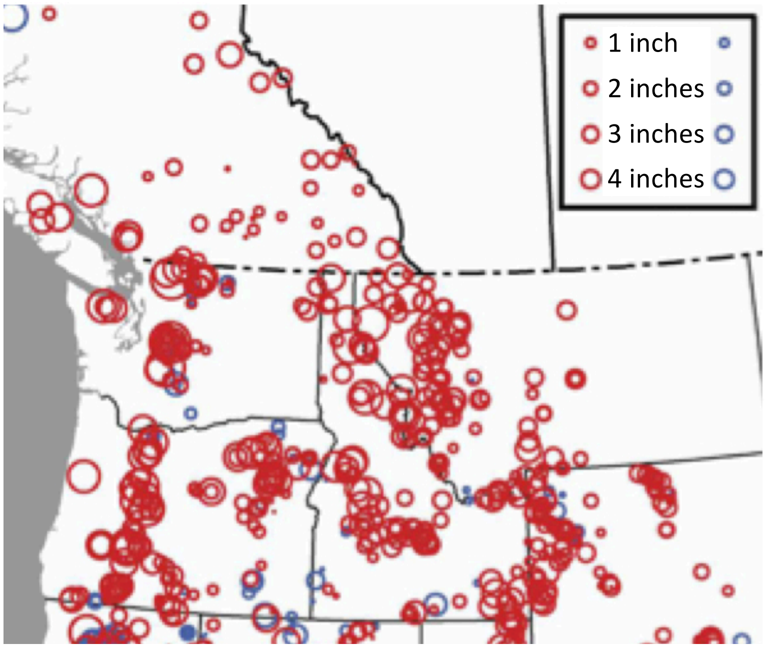


Figure 14. Increases (in blue) and decreases (in red) in April 1st snow-water equivalent (SWE) over the 1960–2002 period of record, adapted from Mote[12].

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.[13] 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,[18] 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

In the northern 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[13]
- Declines in streamflow[16,19,20]
  Diminished recharge of subsurface aquifers that support summer baseflows[17]
- Summer low flows have declined 29% to 47% during the latter half of the twentieth century[21]

Changes in temperature

- Stream temperatures have increased in many areas[22]
- Increased wildfire leads to even more water temperature increase[23]

Changes in storm intensity

- 16% increase in frequency and intensity of very heavy precipitation[24]
- Increased probability of 20-year flood from 1915 to 2003[25]

Changes in seasonal timing

- Rivers and lakes freeze over, on average, 5.8 days later each century[16]
- The ice breakup date is, on average, 6.5 days earlier each century[16]
- Snowmelt and snowmelt-driven runoff also is occurring earlier[26]
- Spring runoff has advanced steadily during the latter half of the twentieth century and now occurs 1 to 3 weeks earlier[20,27]
- Observed streamflow has increased in March and declined in June[20]

A new report by the Bureau of Reclamation projects small increases in runoff for western Montana over the next century.[28] Increases in the heaviest downpours are expected to continue during the coming century.[24]

As temperature increase leads to more rain and less snow, the flood risk is expected to increase in Missoula County.[14] Decreases in snow pack and in the length of the snow season could have serious repercussions to winter recreation and water storage alike. Please see the companion report on climate impacts to socioeconomic systems for more information.

As temperatures and evapo-transpiration increase, summer low flows are expected to become more severe, with longer and lower low flows.[14]

VEGETATION

Much of Missoula County is forested. 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,[29] 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 two vegetation models. The first, the MC1 model, provides projections for suitable climate for predominant vegetation types (see box) rather than individual species. The second approach provides projections for individual species using a "climate envelope" modeling approach.

Currently, neither approach to modeling future vegetation distributions is reliable enough for long term forest planning, due to high levels of uncertainty. Their utility lies in the insight they provide about the potential direction and magnitude of vegetation change that we might see as climate change progresses.

MC1 vegetation type characteristics:

- **Subalpine forest** - Mixed high elevation climax vegetation with a very short growing season. Tree species include Engelmann spruce and subalpine fir.
- **Temperate evergreen needleleaf forest –** Area affected by moist Pacific maritime air masses. Dominant tree species include subalpine fir, Douglas-fir, grand fir, Engelmann spruce, lodgepole pine, western larch, and ponderosa pine.
- **Temperate deciduous broadleaf forest –** Forest dominated by broadleaf deciduous species, such as cottonwood (in riparian areas), quaking aspen, chokecherry, and box elder. Potential new species to the area include oaks and maples.
- **Temperate cool mixed forest –** A mix of dominant needleleaf and broadleaf species.
- **Temperate evergreen needleleaf woodland –** Lower density forest than temperate evergreen needleleaf forest, but with similar composition. Ponderosa pine often dominates.
- **Temperate shrubland –** Sagebrush steppe
- **Temperate grassland –** Foothills prairie

Both vegetation models only make projections for native vegetation and do not account for land use change (i.e. agriculture and development) or introduced species (i.e. non-native grasses). The MC1 dynamic vegetation model provides projections for conditions that support certain types of dominant vegetation. 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 Missoula County, MC1 projects little change in conditions supporting dominant vegetation types. Subalpine forest is expected to contract while temperate evergreen needleleaf forest is expected to expand (Fig. 15).

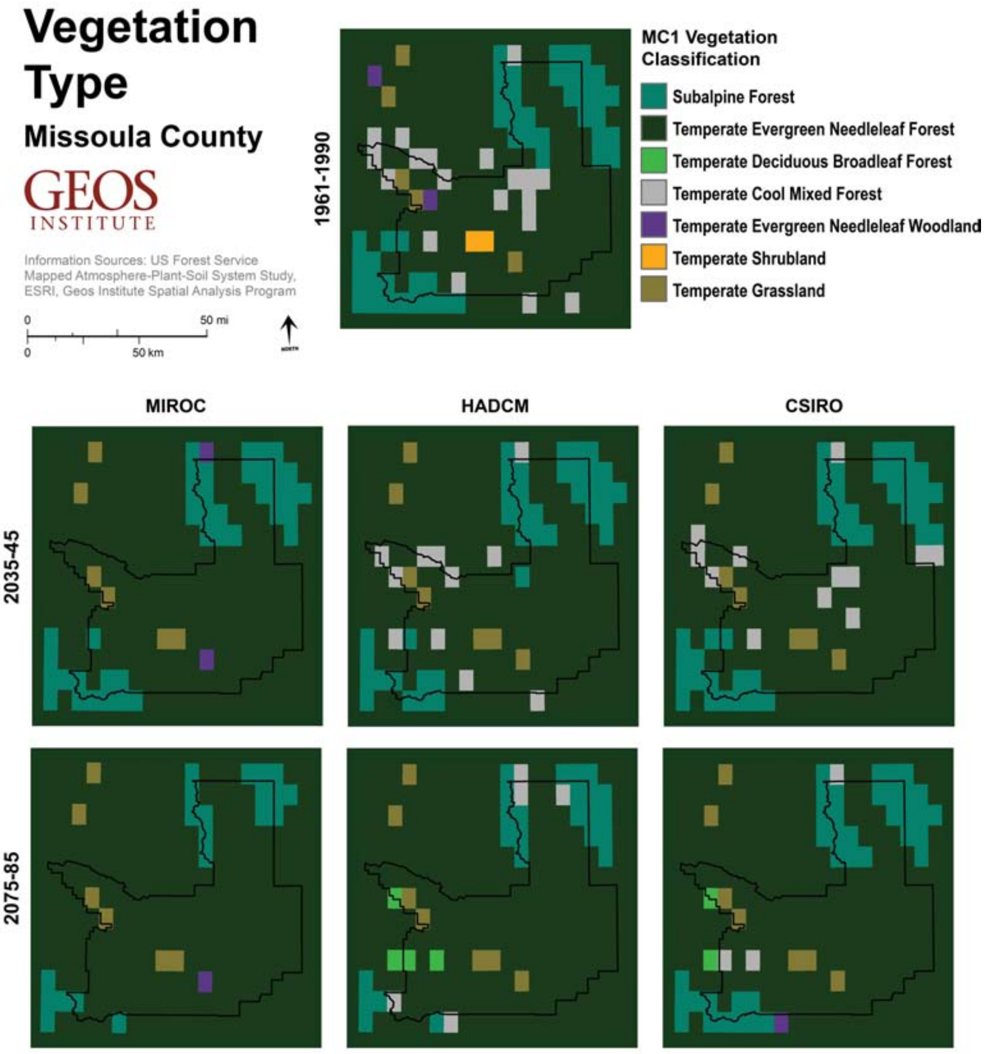


Figure 15. The MC1 model shows suitable growing conditions for native types of vegetation, but not actual vegetation or non-native vegetation. Land-use changes, such as agriculture or housing, are also not reflected in this output. Actual vegetation in the future will depend not only on climate conditions, but also on land use, non-native species, and the time needed for seed dispersal and for new vegetation to become established and reach maturity.

Climate Envelope Model Output – In contrast to the MC1 vegetation model, the climate envelope approach taken by Rehfeldt[30] shows dramatic change in many common tree species in Missoula County.

Scientists at the USDA Rocky Mountain Research Station created model projections for important tree species in the western U.S.[30] Their model identifies climatic conditions that support the current distribution of species and extrapolates what the distribution of those species is likely to be under future projected conditions. Predictor variables for species distributions include the following: summer and winter temperatures, measure of available moisture, length of the frost-free season, and the interactions of temperature and precipitation.

This approach to predicting future distributions of tree species ignores many non-climate relationships that influence where a species is able to thrive. Many species are limited, not by climate, but by competing species, soil type, nutrients, or other factors. None of these limitations are accounted for using the climate envelope approach.

The general patterns revealed by these models suggest that montane forests and grassland communities are likely to thrive at the expense of subalpine, alpine, and tundra communities. In the target area of Missoula County, the Rehfedlt projections were consulted for each of the following tree species as modeled from CGCM3 (Third Generation Couple Global Climate Model), GFDLCM21 (Geophysical Fluid Dynamics Laboratory Climate Model), and the HADCM3 (Hadley Center Climate Model for 3rd IPCC Assessment Report). The scenario reported here is A2, the same scenario we used above.

Ponderosa pine (*Pinus ponderosa*) is relatively abundant in areas of Lolo National Forest and other parts of the county. According to all three climate models, conditions favorable for this species will be markedly reduced.

Douglas-fir (*Pseudotsuga menziesii)* currently occurs throughout most of Missoula County at higher elevations. According to all three climate models, conditions favorable for this species will be markedly reduced.

Engelmann spruce (Picea englemannii) is currently most abundant in the northeast and southwest parts of the county. The model suggests that the northeastern portion of the county is more likely to maintain viable conditions for this species than the southwestern portion.

Lodgepole pine (*Pinus contorta*) is found throughout the county at higher elevations. According to all three climate models, conditions favorable for this species will be markedly reduced.

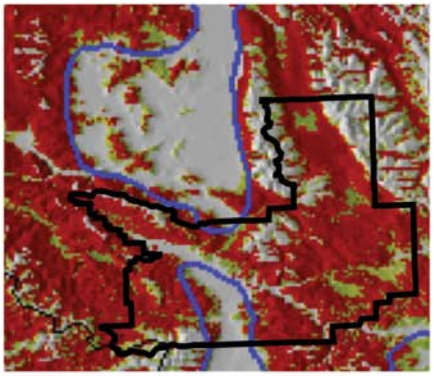
Western larch (*Larix occidentalis*) can be found throughout the county at higher elevations. According to all three climate models, conditions favorable for this species will be markedly reduced, but some favorable conditions could persist at higher elevations.

Subalpine fir (*Abies lasiocarpa*) is currently found in higher elevations through most of the area. All models suggest that conditions could become markedly unfavorable through the century.

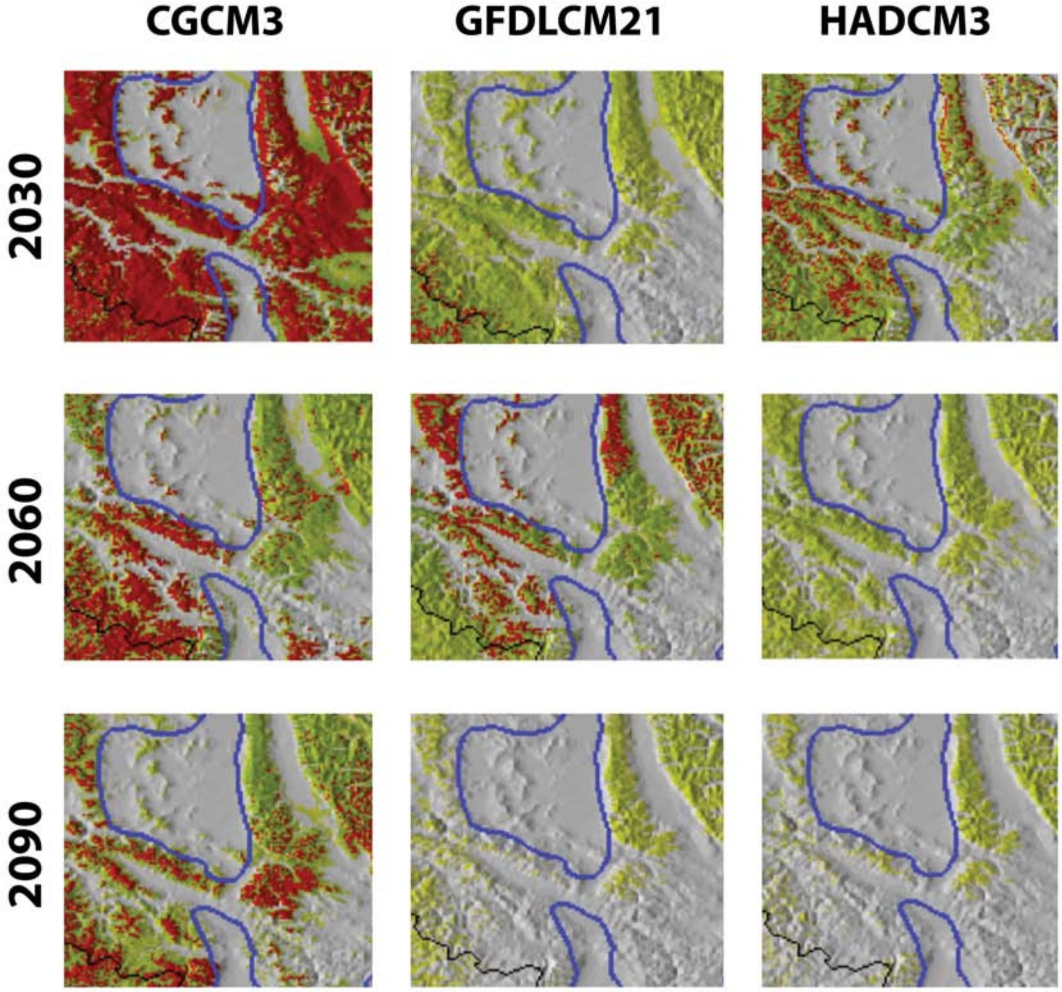
Quaking aspen (*Populous tremuloides*) finds only marginal conditions currently through much of the area. According to all three climate models, conditions favorable for this species will be markedly reduced.

Gambel oak (*Quercus gambelli)* is considered because the Rehfedlt models suggest a northern expansion of conditions for this species from the current focus in the south central U.S. (New Mexcio/Colorado and south). Two of the models suggest that favorable conditions will appear to the east and southeast of the county by 2090. The spread of Gambel oak north and into Montana answers to some extent at least, the question of what might replace the conifer species that are likely to decline over longer time frames.

Figure 16. Current and future projected range of Douglas-fir in the Missoula County area, based on three climate models and three future time periods. Red indicates areas expected to have high viability while light green indicates areas expected to have moderate viability. For reference, an approximate outline of Missoula County was overlaid on the map of current range.



Current range



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.[31] Wildfire is also closely associated with large scale climate patterns such as El Niño.[29,30,31]

Wildfire in the West follows a strong seasonal pattern, with 94% of fires and 98% of area burned occurring between May and October.[35] In western Montana, 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.[31]

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; Figure 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.[35] The greatest increase in wildfire frequency has been in the Northern Rockies.[31,35]

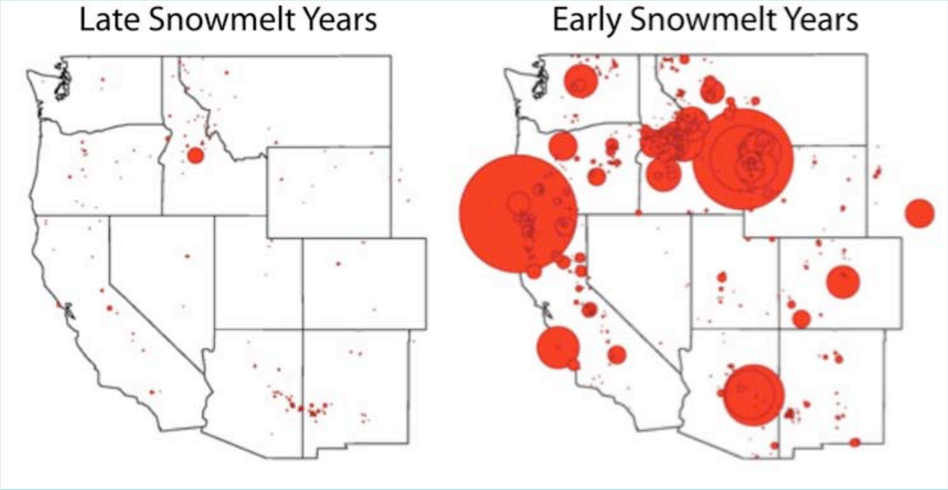


Figure 17. Forest Service, Park Service and Bureau of Indian Affairs large forest wildfires (>1000 acres) for years with early or late spring snowmelt, 1972 - 2003. From *Westerling et al 2006.*

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.[31]

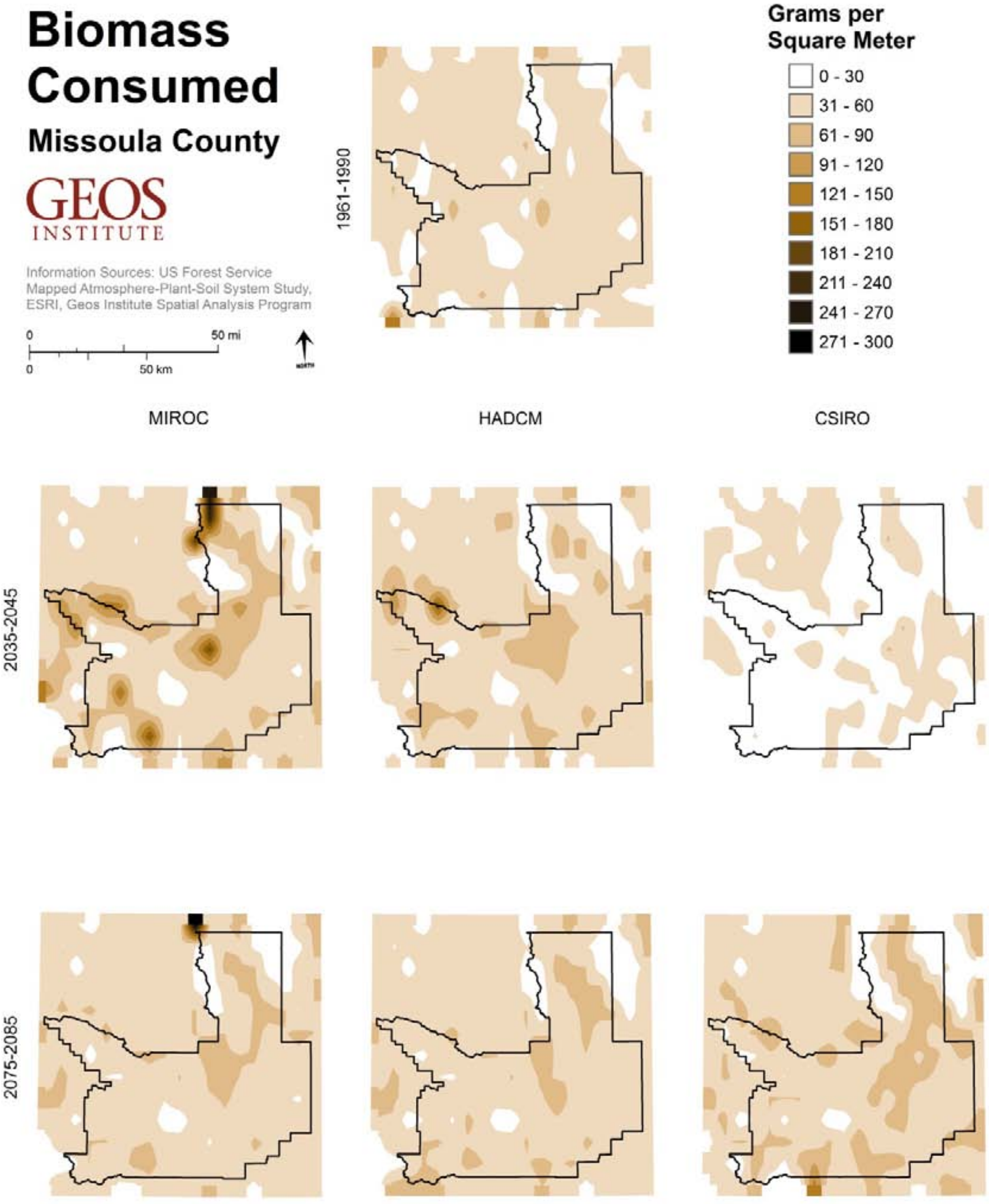
Fire severity can be expected to increase given warmer and drier conditions.[36] An assessment of climate change and forest fires over North America projected 10-50% increases in seasonal severity rating (SSR) over most of the U.S.,[37] implying increases in area burned and fire severity.

Lightning strikes are also expected to increase with increasing CO_2 in the atmosphere[38]. With fire-favorable fuel conditions, increased lightning would yield an increase in the frequency of natural fire occurrence.[34]

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.[36]

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 HADLEY), 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.

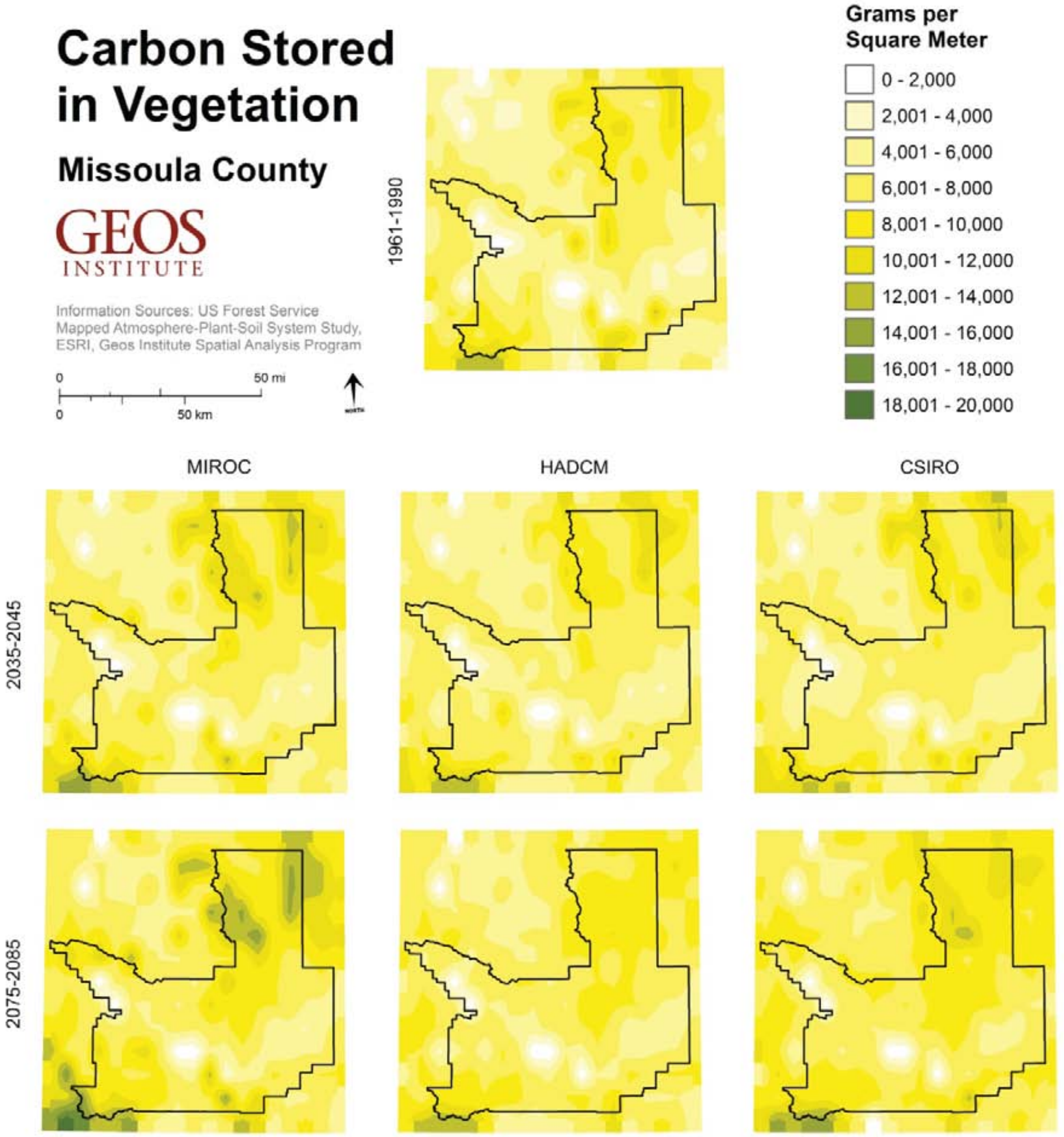
Figure 18. Average annual biomass consumed by wildfire in Missoula County, shown for the historical period (1960-1991) and projected for two future periods (2035-45 and 2075-85), using three global climate models.



CARBON STORED IN VEGETATION

All three global climate models indicate an increase in carbon stored in vegetation by mid-century (+4 to 9%), with continued increase through late century (+11 to 25%). Much of the increase occurs at higher elevations (Fig. 19) where subalpine vegetation is expected to be replaced by temperate evergreen needleleaf forest, and the growing season will be lengthened. Carbon storage is likely to be disrupted as vegetation transitions from one type to another – a detail not reflected in MC1 model output.

Figure 19. Average annual carbon storage in vegetation in Missoula County, shown for the historical period (1960-1991) and projected for two future periods (2035-45 and 2075-85), using three global climate models.



ECOLOGICAL CHANGE

Ecological systems of Missoula County 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.[39]

Wildlife is already responding to climate change on a global scale[40] and is expected to continue to respond. Some documented changes include declines in pika,[41] a species found only at high elevations. In contrast, elk in Montana have experienced improved conditions due to lower snow pack and warmer winters.[42]

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.[43] Approximately 30% of all species could be lost.[44]

Some of the wildlife in Missoula County that is expected to be most vulnerable to climate change includes species dependent on snow, such as wolverine, lynx, and snowshoe hare.[45] Also vulnerable are high-elevation species such as big horn sheep, pika, mountain goat, and wolverine,[46] as well as rosy finch and ptarmigan.[45] 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 bull trout[47] and cutthroat trout[48] (Westslope and Yellowstone). The Rocky Mountain tailed frog, which depends on cold mountain streams, may also be affected.

Changing stream flow patterns, increasingly severe storm runoff, and increasing water temperatures will impact aquatic species. Many trout and salmon 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.[49]

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.

CONCLUSIONS

The purpose of this report is to provide up-to-date climate projections for Missoula County 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 the time period of 2035-2045 are highly likely to become reality.

Whether we limit climate change to this level or continue to progress towards the level projected for 2075-2085 and beyond will depend on whether the U.S. and other key nations choose to lower emissions drastically and immediately.

The projections provided in this report are intended to form the foundation for city, county, and regional adaptation planning for climate change. 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. This process will take place in a series of workshops involving leaders and experts in the following sectors: natural ecosystems (terrestrial and aquatic), built (infrastructure, culverts, etc.), human (health, emergency response, etc.), economic (agriculture, business, etc.) and cultural (Native American tribal customs and rights, immigrant communities and customs, etc.).

The ClimateWise® program is structured to begin the planning process in local communities, and to "scale up" management strategies to the state and federal level by identifying needed changes in policy and governance structure. During the local planning process, experts from different sectors will identify barriers to sound management, allowing us to address these limiting factors by collaborating with lawmakers.

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.

Please contact Marni Koopman at the Geos Institute for more information or to become involved in this process (marni@geosinstitute.org; 541-482-4459 x303).

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