Missoula County-Wide Climate and Community Primer

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Climate Ready Communities: Building Resiliency in Missoula County

by

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Introduction

While climate change is a global challenge, its impacts are experienced at the local level, and it falls to local communities to address them. We are already experiencing the impacts of climate change in Missoula County, and those impacts are projected to intensify over the coming decades and to touch every sector of our county. Changes are likely to include reduced low elevation snowpack, earlier spring snowmelt, more frequent and intense droughts and wildfires, and impacts to agriculture and recreation. The earlier that we understand and prepare for these changes, the greater our chances of mitigating their impacts on human health and safety, the natural environment, and our local economy.

Missoula County, the City of Missoula, and Climate Smart Missoula are working together to lead a county-wide effort to better understand our greatest vulnerabilities in the face of climate change, and to develop a coordinated plan to prepare our county for the changes we are facing. This climate resiliency planning process will unfold over the next 12-16 months and will generally follow the guidelines of the Climate Ready Communities program developed by the Geos Institute (Geos Institute 2017). The process relies on community engagement and will involve a broad range of local stakeholders in fields including public health, emergency services, agriculture, forestry, wildlife, recreation, business, underrepresented communities, and local water, energy, and transportation systems.

This is not the first time that climate adaptation has been considered in Missoula County; indeed, numerous local efforts have addressed this topic either directly or indirectly. The goal of this process is to build from those efforts in a comprehensive and inclusive manner.

This Climate and Community Primer is intended to inform stakeholders involved in the Climate Resiliency Planning process. The Primer includes four main sections:

1. Three mid-century climate scenarios for Missoula County, intended to describe a range of plausible futures that the county could experience in the next 30 years;
2. A brief overview of Missoula County, including its physical setting, demographics, and economy;
3. Climate change projections specific to Missoula County drawn from the Montana Climate Assessment and other sources; and
4. A discussion of the implications of those climate change projections for the county's environment and natural systems, agriculture, cultural resources, human health, and economy.

This Primer does not involve original research but draws on the wealth of information available on these topics, including the Montana Climate Assessment, the City and County Growth Policies, the Community Health Assessment, the Pre-Disaster Mitigation Plan, the Community Wildfire Protection Plan, scientific papers, and many other resources (see Works Cited for a complete list).

Mid-Century Climate Scenarios for Missoula County

The three scenarios below describe plausible futures for Missoula County based on current trends, recent events, scientific research, and climate projections (citations available upon request). These are **plausible** futures that Missoula County **could** face in the next **30 years**. Scenarios are used in planning for climate adaptation as a way to tangibly represent key uncertainties related to a) projected changes in temperature and precipitation at the local scale, and b) the implications of those changes for ecosystems and human communities. The goal is to provide detailed descriptions of what the future could look like to help people identify specific challenges and opportunities within different sectors and communities across the county. Scenarios also enable us to prepare for the range of futures that climate change might bring to Missoula County.

The scenarios below were reviewed by seven subject matter experts to ensure that they reflect the latest science on current and projected climate impacts. Refer to subsequent sections of this primer for additional detail on many of the impacts mentioned in the scenarios.

This is not intended to be an exhaustive depiction of plausible impacts. We will use these scenarios in the workshops as a starting point for conversations about the changes Missoula County could face, to identify additional impacts, and to start developing strategies to prepare for these changes.

Scenario 1: Turn Up the Heat

In this scenario, the annual average temperature increases by approximately 6°F by mid-century, with the greatest temperature increase in the summer (about 7°F, versus 5°F the rest of the year). This is similar to the present day average annual temperature in Denver, Colorado, 500 miles south of Missoula. Average summer temperatures will be hotter than the summer of 2017, when we experienced a prolonged heat wave. We'll experience 2-3 additional weeks per year with daily high temperatures above 90°F. Average annual precipitation will remain about the same, but the timing of precipitation will change: summers will be drier and the rest of the year slightly wetter. On average, summer rainfall will decrease by about 30%.

Fire and Smoke

With higher temperatures and less precipitation in the summer and early fall, fire seasons will last an average of 12 days longer than they do today, and the total land area burned each year will increase about 50% on average. While we will not see extensive, region-wide burning every year, fire seasons like 2012 and 2017, which saw widespread burning across the northern Rockies, will become more frequent.

Wildfires will pose an increasing threat to the lives and properties of Missoula County residents, in particular those who reside in the wildland-urban interface (which encompasses nearly all inhabited areas of Missoula County, with the exception of the Missoula urban core).

Over time, increases in the size and severity of fires will reduce the extent of low elevation forests, converting forested areas to shrublands or grasslands. Invasive species such as leafy

spurge and spotted knapweed thrive in areas that have been recently disturbed and will increase their range as a result of more area burned. Warmer winters will also promote larger pine beetle populations.

Longer and more intense fire seasons in Missoula County and throughout the region will mean longer periods of unhealthy air quality due to wildfire smoke, increasing the incidence and severity of respiratory and cardiovascular disease among county residents. Emergency room visits for breathing problems, heart attacks, and strokes will spike during periods of dense wildfire smoke. Children, the elderly, people with heart and lung disease, and outdoor workers will be among the most impacted. The smoke season will last well into September, and possibly October, with increasing impacts on schools and fall athletic programs. Outdoor recreation and tourism will decline during periods of wildfire smoke. Portions of Yellowstone and Glacier National Parks will close more frequently due to wildfires; and even when the parks are open, wildfire smoke will obscure vistas and deter tourists. Thousands of jobs will be lost in the tourism industry statewide.

Water

Warmer winters will lead to a decline in mountain snowpack. That snowpack will melt earlier due to warmer spring temperatures, leading to peak streamflows 2-3 weeks earlier in the year. Late summer streamflows will be much lower than they are now, reducing the amount of water available for fish and riparian vegetation. In addition, lower flows combined with hotter summers will mean higher river temperatures, reducing populations of temperature-sensitive species such as bull trout. Higher river temperatures will lead to more frequent and longer-lasting "hoot owl" fishing restrictions, which prohibit fishing during certain hours of the day in order to minimize stress on trout when water temperatures are high. Warming water temperatures may also result in the proliferation of parasites, viruses, fungal infections, and algae blooms, impairing water quality, affecting aquatic plants, and killing fish.

Due to a later fall freeze and earlier spring thaw, the growing season will increase in length by about 2 months. While annual precipitation does not change in this scenario, warmer temperatures will result in increased evaporation, reducing the water available for plant growth by 4-8%. In addition, less summer precipitation and lower August streamflows will mean that less water is available for agriculture during the growing season. The longer growing season could be beneficial to irrigated agricultural producers in the county, as long as they have adequate access to water for irrigation. Warmer temperatures might also benefit the nascent viticulture industry in Missoula County. However, some crops may be damaged by heat stress due to hotter summer temperatures, and ranchers will experience decreased forage production and an increase in invasive species on rangelands.

Reduced snowpack and earlier snowmelt will impact winter recreation. For example, Snowbowl will face shorter ski seasons and more frequent closures of low-elevation terrain, and opportunities for low-elevation nordic skiing and backyard ice skating will be reduced or eliminated. Seasons for other recreational sports such as mountain biking may be extended due to warmer springs and falls, but will also be affected by wildfire smoke.

Scenario 2: Here Comes the Rain Again

In this scenario, average annual temperatures increase by about 3°F by mid-century (about half as much as in Scenario 1), and we experience roughly one additional week per year with daily high temperatures above 90°F. Average annual precipitation increases by 15%. This additional precipitation falls in the winter, spring, and fall; summer precipitation does not change. We also experience several more days per year of intense rainfall.

There will be an increase in the number and intensity of droughts and wildfires in this scenario, but not as pronounced as the increase as in Scenario 1 *Turn up the Heat*. On the other hand, flooding will be a much bigger issue in this scenario than in Scenario 1.

Changing Seasons

While summer precipitation does not change in this scenario, hotter summers increase evaporation rates, reducing water available for plant growth in the summer and resulting in a greater contrast between wet and dry seasons. Early but short spring rains promote rapid green-ups, followed by prolonged dry summers and brown landscapes.

The growing season increases in length by 2-3 weeks due to increased fall and spring temperatures. These conditions will expand not only the growing season, but also the types of crops we can grow in Missoula County, as well as affecting the timing of planting, fertilizer application, and harvest.

Elk and other wildlife will benefit from the availability of ample forage in early spring, but may be forced to change their normal winter ranges due to warmer winters and deeper mountain snowpack.

Flooding

Throughout Montana's history, "rain on snow" events have caused the most severe and destructive floods. In this scenario, warmer temperatures and wetter winters and springs will cause more rain on snow events and faster snowmelt, leading to more frequent and severe flooding. By mid-century, the average winter and spring will be even warmer and wetter than 2018, when the Clark Fork River crested at its second highest level in 100 years and severe flooding damaged houses and tipped power poles.

More frequent and severe flooding will lead to extensive property damage and pose a risk to the health and safety of the hundreds of Missoula County residents who live or work in the floodplain. Flooding will also increase the incidence of waterborne illness such as giardia.

In the urban area, more severe rain events will challenge our stormwater system, and greater volumes of stormwater runoff that flow to the aquifer will increase the potential for contamination of our drinking water supply.

Flooding will impact populations of fall spawning fishes, such as bull trout, whose eggs and young are vulnerable to spring floods.

Scenario 3: Feast or Famine

In this scenario, average temperatures will increase 4-5°F by mid-century and we'll experience about two more weeks each summer with daily temperatures above 90°F. Average annual precipitation will not change, but there will be much greater variability in precipitation from year to year, with some very wet years and some intense drought years. An "average" year will be a thing of the past.

Variability

On average, the total area burned by wildfires each year will be larger than it is today but smaller than in Scenario 1 *Turn Up the Heat*. Increased year-to-year variability in precipitation will result in increased variability in fire season length and area burned. Intense rainfall will reduce total area burned in some years, depending on the timing within the fire season. The timing of season-ending events, in particular, will be highly variable among years.

In dry years, we will experience low late-summer streamflows and reduced water available for plant growth, with impacts on aquatic ecosystems, river recreation, and agriculture similar to Scenario 1.

In wet years we will experience flood events similar to those described in Scenario 2 *Here Comes the Rain Again*. Flooding will be exacerbated by the increase in wildfires in dry years, since rainfall runoff over burned areas can cause flash flooding. Burned hillsides are also vulnerable to landslides when it rains, resulting in soil loss which degrades land, slows regrowth, and leads to excessive sedimentation in streams and rivers.

From year to year, the season and conditions for outdoor activities like skiing and fishing will vary dramatically. Businesses involved in outdoor recreation and those that cater to tourists will be particularly challenged to prepare for this unpredictability. Increased variability will also be difficult for farmers and ranchers in the county, as the strategies for drought years may be very different from wet years. Indeed, not being able to plan for an "average year" can be difficult for many, from athletes (youth to adult) to construction firms. Being forced to alter schedules and expectations each season can be stressful and economically costly.

Ecosystems

Extreme conditions such as long winters with heavy snowfall and summer drought are hard on fish and wildlife. For example, elk distributions will change due to long winters in some years and dry summers in other years. Fish that spawn in the fall are vulnerable to spring flooding; and all fish species are stressed by low summer flows and warmer river temperatures.

Overview of Missoula County

Physical Setting[1]

Missoula County is located in western Montana and is the second most populous county in the state. The county has a population of 117,441 (2017 U.S. Census estimate) and an area of 2,593 square miles. The City of Missoula is the only incorporated city and serves as the county seat. More than 60% of Missoula County residents live in the City of Missoula, and more than 80% of county residents live in the Missoula urban area. Unincorporated communities in Missoula County include Bonner-West Riverside, Clinton, Condon, East Missoula, Evaro, Frenchtown, Greenough, Huson, Lolo, Milltown, Orchard Homes, Potomac, Seeley Lake, and Turah. The north-central portion of the county is part of the Flathead Reservation which is home to the Confederated Salish and Kootenai Tribes (CSKT).

The forested mountains that frame the valleys and the open spaces that extend across the valley floors are iconic of Missoula County. Over 1,975 miles of rivers, streams and named tributaries crisscross the valleys. The City of Missoula is located at the base of Mount Sentinel at the hub of five valleys and three rivers (the Blackfoot, the Bitterroot, and the Clark Fork). The Seeley Lake area is located in the Clearwater River watershed, with a chain of lakes running through the valley and forested mountain ranges on either side. The northernmost portion of the county, which includes Condon, is in the Swan River Valley.

Almost 63 percent of the land in Missoula County is managed by state, federal and local governments, with tribal lands accounting for an additional 6 percent. The U.S. Forest Service is the largest landowner, with 51 percent of county land area, followed by the State of Montana at 9 percent. **Figure 1** shows the distribution of these lands across the county.

[1] This section is adapted from the 2017 Update to the Pre-Disaster Mitigation Plan (Missoula County Office of Emergency Management 2017).

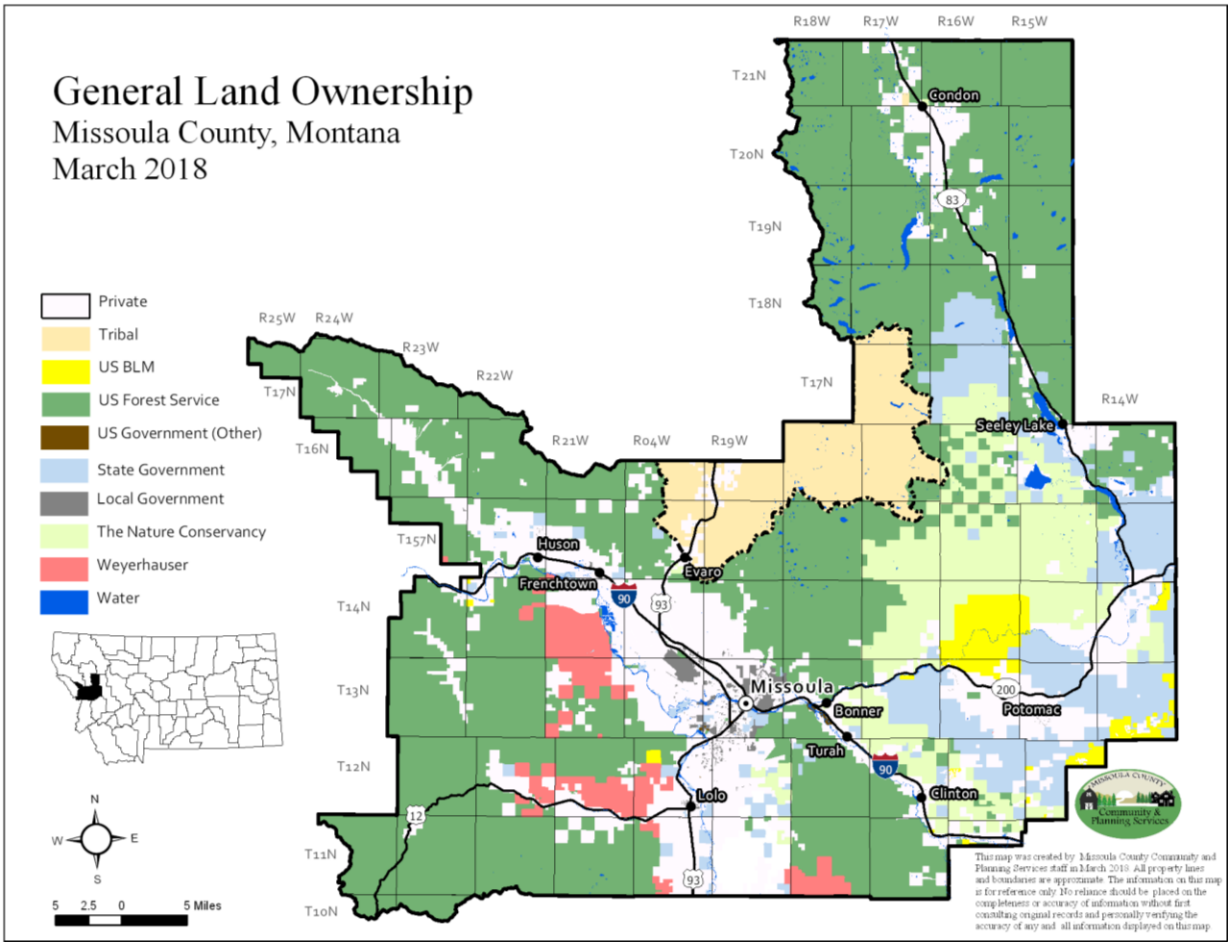

Figure 1. Land Ownership in Missoula County, Montana

Approximately half of Missoula County land cover is classified as forest. Other major categories of land cover include "recently disturbed or modified" (recently burned or logged areas), grasslands, water and riparian systems, and human land uses including agriculture and urban areas (Montana Natural Heritage Program 2017a). **Figure 2** shows land cover distributions across Missoula County.

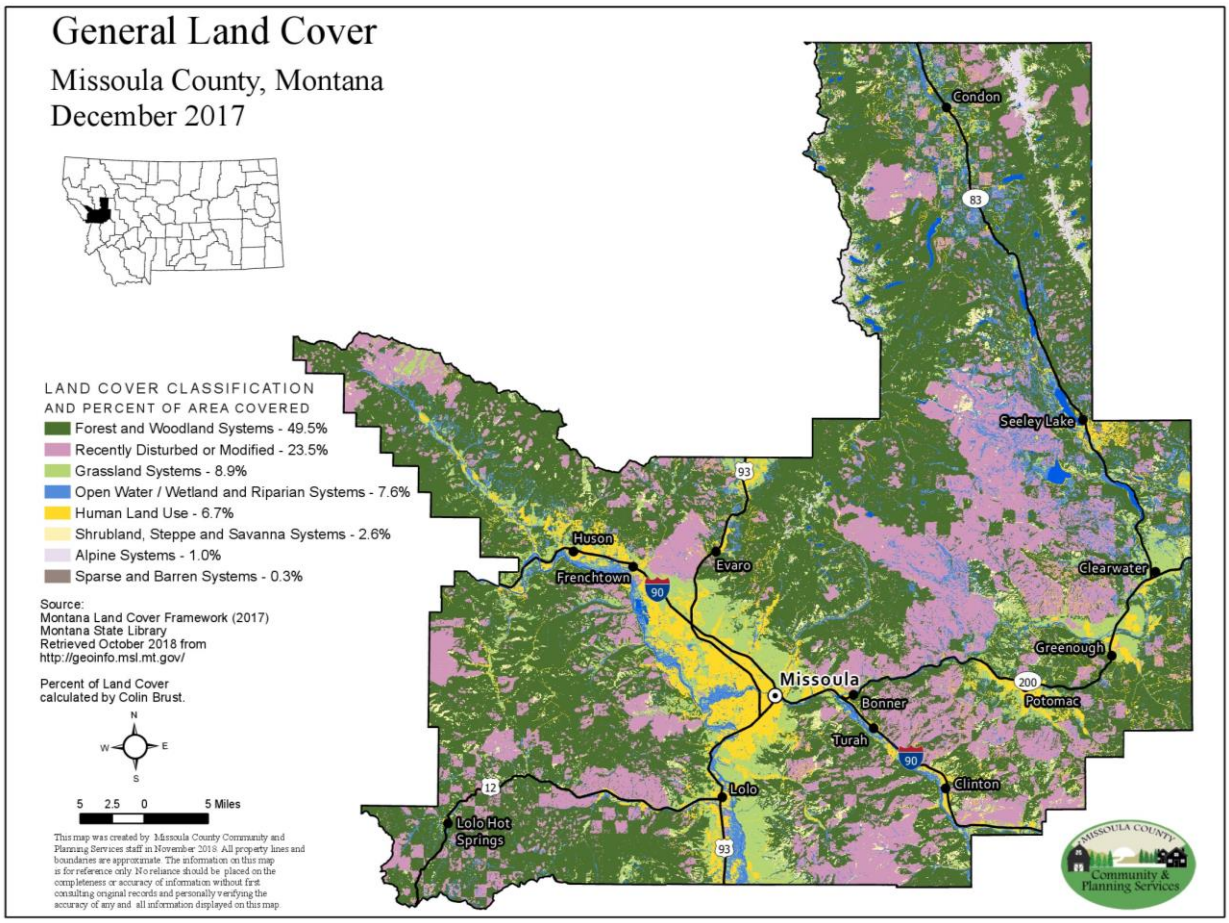

Figure 2. Land Cover in Missoula County, Montana

Because of its gradient from mountain tops to valley bottoms, there are various types of ecological systems within Missoula County. These include conifer-dominated forest and woodland systems, montane grassland systems, and floodplain and riparian systems (Montana Natural Heritage Program 2018). These systems are described further in the Land Systems section beginning on page 23.

Demographics

The county is expected to grow from its current population of 117,441 to 137,055 by 2035. The highest rate of growth is expected in the 65+ age group (Missoula County 2016).

Growth rate is not uniform across the county; among the smaller communities, Lolo is growing the fastest, while Seeley Lake is losing population. Age distributions also vary across the county. The populations of Seeley Lake and Condon are older than the county as a whole, while the populations of Frenchtown, Lolo, Turah, Clinton, and Bonner are younger (Missoula City-County Health Department 2017a).

Missoula County has a largely white population, with 92.1% of residents identifying as white. The second largest racial category in the county is Native American, accounting for 2.5% of residents. These percentages are relatively uniform across the county, with the exception of Evaro, where 38.1% of residents identify as Native American (Missoula City-County Health Department 2017a). Evaro is located on the Flathead Indian Reservation.

Economy

The City of Missoula serves as the economic hub not only of the county, but of the entire region. Of the more than 76,000 jobs in Missoula County in 2013, less than 6,000 jobs were located outside of the city. The local economy was historically fueled by timber production and agriculture, and while these industries are still important, the economy has been changing rapidly. Today, health care, education, retail and wholesale trade, tourism, government, professional, technical and business services, and construction are the largest income generating industries in the county (Missoula County 2016). More than 20% of Missoula County jobs are related to travel and tourism (Headwaters Economics 2018), much of it associated with the county's outdoor recreational opportunities and its location between Glacier and Yellowstone National Parks.

The unemployment rate in the county was 2.8% as of August 2018, below the national rate of 3.9% (Montana Department of Labor and Industry 2018). Missoula County residents are well educated, with 41.8% holding Bachelor's degrees or higher, compared to 30.3% nationwide (Headwaters Economics 2018). However, the median household income in the county is $46,371, significantly lower than the US average of $55,322. The median household income in the City of Missoula is even lower, at $42,389. Poverty rates are higher than nationwide, with 16.1% of county residents (and 19.3% of city residents) living below the poverty line, versus 15.1% nationwide. Poverty rates in the county are higher among Native Americans (32.1%) than whites (15.5%) (Headwaters Economics 2018).

Housing

Housing affordability is an increasing concern in Missoula County. As the county population grows and household size (number of people per household) shrinks, there is increasing pressure on the county's housing stock, particularly in the urban area. As of 2016, about 25% of homeowners and 47% of renters in Missoula County were "cost burdened," meaning that they pay more than 30% of their income for housing (Missoula Organization of Realtors 2018). Housing prices have increased faster than incomes over the last decade, resulting in an increased number of cost burdened households.

The median home sale price in the Missoula urban area jumped 34% from 2010 to 2017, to $268,250. It would take an income of about $66,000 a year to afford the median-priced home, well above Missoula County's median household income of $46,371 (Missoula Organization of Realtors 2018).

Over the past several years both the city and county have had rental vacancy rates below 5%, indicating the need for additional rental housing stock (Werwath Associates 2018). However, the construction of several large multifamily housing projects in the Missoula urban area in 2018 appears to have eased pressure on the rental market.

More than 5,000 people, or about 8% of the Missoula County workforce, commute from neighboring counties (mostly Ravalli County), due in part to lower housing prices in these areas.

Homelessness is an ongoing concern in Missoula County, and in 2011 the city and county jointly developed "Reaching Home: Missoula's 10 Year Plan to End Homelessness." A point-in-time survey in January 2017 identified 344 homeless individuals in Missoula, and the number of homeless children in Missoula County Public Schools was estimated at 438 during the 2016-17 school year (Missoula Organization of Realtors 2018).

Infrastructure

Water

The City of Missoula water system, acquired from the private Mountain Water Company in 2017, is the largest public water supply in Missoula County. It serves over 56,000 residents, pulling water from the Missoula aquifer via 37 wells. The next largest water systems are the Lolo Water District, which serves about 2,600 residents in the community of Lolo, and the Seeley Lake Water District, which provides treated surface water to almost 1,400 residents (Montana Department of Environmental Quality 2018). Another 12,000 residents get their drinking water from 82 smaller community public water systems. The rest of Missoula County residents are served by private water supplies, typically from individual wells.

The Missoula aquifer provides water for 80 percent of Missoula County residents; the rest are served by smaller aquifers, rock and clay groundwater systems, springs, surface water or, for a small percentage of the population, water hauled to the site and stored in cisterns. In the valleys, alluvial aquifers (those with sand and gravel base) tend to be prolific and productive, but in some areas of the County, wells drilled into bedrock or clay groundwater systems are less productive.

Filed water rights in parts of Missoula County exceed the amount of surface water available. As a result, the Montana Department of Natural Resources cannot approve new water rights, without proof of mitigation, in Grant Creek, Hayes Creek, the Clark Fork above the confluence of the Blackfoot River, and the entire Bitterroot River. Because DNRC recognizes that groundwater and surface water are connected, this prohibition affects both wells and surface water draws. However, since individual wells below established withdrawal thresholds are exempt from water right requirements, new development on individual wells continues to occur in most of these areas.

Stormwater

When rain and melting snow run across hard surfaces such as rooftops, roads and parking lots, they pick up pollutants which they then carry into the county's rivers, streams, lakes, and aquifers. Common pollutants in stormwater runoff include fertilizers, pesticides, oil, grease, detergents, and metals, all of which harm water quality and aquatic plants and animals. The Montana Department of Environmental Quality identifies the Bitterroot River as the only surface water in Missoula County with specific impairments caused by stormwater. However, non-point source contamination is the leading cause of the remaining water quality impairments throughout the county and the state.

The Missoula Water Quality Ordinance (Missoula Municipal Code Chapter 13.26) is intended to protect water quality within the city limits and 5 miles beyond city limits. The Missoula Valley Water Quality District responds to reports of illicit discharges to storm drains, soil, and water bodies. The county's Stormwater Management Plan calls for continuing public education, detection and elimination of illicit discharges, control of construction site stormwater runoff, and regulation of post-construction stormwater management in new development and redevelopment (Missoula County MS4 Committee 2017). The City of Missoula's Storm Water Utility, formed in 2016, is responsible for operating and maintaining stormwater infrastructure in the city.

Rain that falls on natural, undeveloped areas is primarily absorbed by the soil. "Green infrastructure" refers to the use of vegetation, soils, and other natural elements to reduce stormwater runoff, while also providing habitat, flood protection, and cleaner water for the community. Outside the Missoula urban area, most stormwater runoff from roads in the county is managed through swales: shallow grassy channels that run alongside roads and absorb stormwater. In addition, stormwater injection wells, or sumps, are used to infiltrate water into the ground rather than direct it to surface water.

Wastewater

The City of Missoula operates the Missoula Wastewater Treatment Facility, which services most of the urban area, East Missoula, and west along the interstate as far as the Wye. The Missoula County Public Works Department runs the Lolo Wastewater Treatment Plant. Together these public sewer systems serve about 66% of the households in the County. The rest of the households in the county use onsite wastewater systems, although plans for a public sewer system in Seeley Lake are under development.

Transportation

There are about 350 miles of public roadway in the City of Missoula and an additional 1,500 miles of roadway in the county outside city limits, as well as 2,400 miles of US Forest Service roads. The Missoula International Airport is served by four airlines and provides nonstop flights to 12 destinations. There are small airports in Seeley Lake and Rock Creek. Montana Rail Link and Burlington Northern-Santa Fe move freight through Missoula County. According to Montana Rail Link, about 16 to 20 freight trains pass through Missoula daily (Missoula County 2016). Passenger rail service is not available in the county.

More than 70% of Missoula County residents commute to work alone, driving their own vehicle (United States Census Bureau 2017). However, there are a number of alternative transportation methods available, especially for residents of the urban area. The Mountain Line bus system offers 13 fixed routes, primarily within in the urban area, and has provided fare-free service since 2015. In 2017 Mountain Line provided over 1.5 million rides. Mountain Line also operates ADA Comparable Paratransit service and Senior Van service for eligible passengers within a ¾ mile radius of existing fixed routes. The University of Montana's UDASH bus system is also fare-free and serves mostly university students. The Missoula Ravalli Transportation Management Association offers fee-for-service van pooling connecting Missoula with Ravalli and Lake Counties.

There is extensive bicycle infrastructure in the urban area, including bike lanes, protected bike lanes, and shared use paths. The League of American Bicyclists has designated Missoula a Gold-Level Bicycle Friendly Community. Missoula's Long-Range Transportation Plan, titled "Activate Missoula 2045," sets a goal of reducing drive-alone trips by one-third through tripling the number of trips taken by bike, walking, and transit (Activate Missoula 2045). The City's Missoula in Motion program works with non-profits, businesses and residents to make progress toward that goal.

Energy

Three electric service providers operate in Missoula County: investor-owned utility NorthWestern Energy serves the Missoula urban area, Missoula Electric Cooperative serves much of the rural area of the county, and Mission Valley Power, which is a federal utility operated by the Confederated Salish and Kootenai Tribes, serves the Flathead Indian Reservation. These providers supply electricity from a variety of sources including hydroelectric dams, coal-fired power plants, natural gas-fired power plants, and wind farms. With the exception of a small amount of solar energy (see Renewable Energy section, below), none of these generation sources are located within Missoula County.

NorthWestern Energy supplies natural gas to the majority of households in the county. Residents of rural areas that are not served by natural gas lines utilize electricity, propane, and/or wood for heating. Overall, 7 percent of Missoula County households use propane as their primary heat source, and 6 percent use wood as their primary heat source (United States Census Bureau 2016).

Historically, woodstoves and fireplaces have been the primary cause of poor winter air quality in Missoula County, since winter temperature inversions trap air pollution on the valley floors. Today the Missoula City-County Health Department regulates the installation and use of woodstoves and fireplaces throughout the county, with the most stringent regulations in the "Missoula Air Stagnation Zone," which encompasses the city of Missoula and about four miles outside city limits in every direction. Today, the Missoula valley meets the federal ambient air quality standards for fine particulates, but the small community of Seeley Lake experiences exceedances of the standards almost every winter because of woodstove smoke.

Renewable Energy

Renewable energy development is accelerating worldwide due to climate change policies as well as the dropping costs of many renewable energy technologies.

As of 2016 there were about 250 small customer-owned solar energy systems on homes and businesses in Missoula County (Montana Renewable Energy Association 2016), and that number continues to grow. In addition, Missoula Electric Cooperative operates three 50 kilowatt "community solar" projects, the output of which it sells to participating co-op members. Google's Project Sunroof estimates that 83 percent of buildings in Missoula County are viable for solar panels based on roof orientation, size, and shading (Google 2018). If solar were installed on all those rooftops, it would provide enough electricity for about 34,000 households, or 72 percent of households in the county.

The state of Montana is ranked in the top five among all U.S. states for wind energy potential. However, that potential is located in central and eastern Montana. Wind speeds in Western Montana, including Missoula County, are not suitable for wind energy development.

Much of Missoula County is forested, and over the years there has been interest in expanding the use of biomass as an energy source. An effort to develop a biomass boiler at the University of Montana in 2011 ultimately failed as a result of the high cost of sourcing and transporting appropriate biomass material in comparison to the low price of natural gas, as well as concerns about its impact on air quality.

Climate Change Projections

Climate change will affect all parts of the globe, but not all will be affected in the same way. Some areas will be most impacted by sea level rise, others by extreme heat, others by drought or flooding or wildfire. Our discussion of climate resiliency must therefore begin with an in-depth understanding of historical climate conditions and projected climate trends here, in Missoula County. This chapter aims to provide that understanding, given what we know today.

In brief: Missoula County's summers are expected to become hotter and drier. Winters and springs are expected to become warmer and wetter. More precipitation will fall as rain instead of snow, especially at low elevations. These changes will directly impact our quality of life and the local economy. For example, warmer, drier summers increase the risk of wildfires and wildfire smoke that damages pulmonary and respiratory health and deters tourists. Prolonged periods of high temperatures increase the risk of heat-related illnesses. Changes in temperature and precipitation patterns affect Missoula County's water resources and the wildlife, agriculture, and recreation economies that depend on them.

While there is much that we can say with confidence about how our climate is changing, any effort to predict the future is accompanied by uncertainty. In climate modeling, this uncertainty stems from the fact that the models themselves are by necessity simplifications of reality, as well as uncertainty about whether and how quickly greenhouse gas emissions will be reduced worldwide. The projections presented in this section are based on the results of twenty different climate models in order to account for the uncertainty that accompanies any one model. We also present results for two greenhouse gas emissions trajectories, one in which emissions are reduced substantially in the coming decades, and another in which they continue to increase (see Climate Models section). In addition, **we address the uncertainty in climate projections directly through three plausible mid-century climate scenarios presented on pages 2-5 of this primer.** These scenarios illustrate a variety of possible futures for Missoula County based on the climate projections presented in this chapter.

This chapter begins with a discussion of climate basics and the data sources used in this project. It then describes historical trends and future projections for temperature and precipitation in Missoula County. The implications of these temperature and precipitation changes for Missoula County's environment and natural resources, agriculture, cultural resources, human health, and economy are discussed in later chapters.

Climate Basics

What's the difference between weather and climate? Weather refers to the condition of the atmosphere at a given time and place, usually a short period of time lasting from minutes to months. Climate, on the other hand, refers to average weather conditions of a region over a longer period of time. The World Meteorological Organization describes climate using a minimum period of 30 year averages, but climate can also be broadly described over hundreds to millions of years (World Meteorological Association 2017). Climate may also be described by the magnitude and frequency of extreme weather events like flooding or droughts. Climate change, therefore, refers to long-term changes in average weather conditions.

Earth's climate and weather systems are powered by the radiant energy of the sun. Most of that energy is either reflected back out to space or absorbed by the Earth's surface, but about 20% of it is absorbed by gases in the Earth's atmosphere. Some of the energy absorbed in the atmosphere is radiated back toward the Earth's surface, further heating the land and oceans. This process by which the atmosphere absorbs and radiates solar energy is known as the "greenhouse effect." The gases that contribute to the greenhouse effect, known as greenhouse gases, include carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3).[2]

The Earth's climate is inherently dynamic and has been changing throughout the planet's history. Past climate changes have been associated with natural causes such as changes in the Earth's orbit, volcanic activity, and gradual, periodic shifts in the atmosphere's greenhouse gas concentrations. However, the recent change in Earth's climate has been largely, if not entirely, caused by human activity, in particular greenhouse gases emitted by the combustion of fossil fuels (coal, oil, and natural gas) that we use to fuel our cars and trucks, heat our buildings, and produce electricity. Since 1750, atmospheric concentrations of CO_2, N_2O, and CH_4 have increased by 40%, 20%, and 150%, respectively, to levels that are unprecedented in at least the past 800,000 years (Intergovernmental Panel on Climate Change 2014). For comparison, an equivalent natural increase in greenhouse gases during the end of the past ice age took over 5,000 years.

Data Sources

The Montana Climate Assessment (Whitlock et al. 2017), a project of the Montana Institute on Ecosystems, was completed in 2017 following two years of work by a team of researchers at the University of Montana and Montana State University. The Montana Climate Assessment includes climate projections for seven climate divisions across the state (Missoula County falls within the northwestern climate division), as well as chapters addressing the impacts of climate change on Montana's water, forests, and agriculture.

This primer draws heavily from the Montana Climate Assessment. In addition, for climate projections specific to Missoula County, we made use of the Climate Explorer, a web application built to accompany the U.S. Climate Resilience Toolkit developed by the National Oceanic and Atmospheric Administration in partnership with twelve other federal agencies (United States Global Change Research Program 2018). For current and historical conditions, we used the Climate Explorer's observational data along with NOAA's Climate at a Glance web application, which is gathered from local weather stations for the years 1950-2013. For future projections, we used the Climate Explorer's modeled projected data.

Climate Models

Climate scientists use complex computer models, called general circulation models, to make climate change projections by simulating interactions in the atmosphere, land, and oceans. Our data sources for this project, including both the Montana Climate Assessment and the Climate Explorer, use data from an ensemble of general circulation models known as the Coupled Model

[2] Water vapor is also a greenhouse gas, but because of its short residence time in the atmosphere (days, as opposed to decades or centuries for the other greenhouse gases) it is not a cause of climate change. However, water vapor can amplify the effects of climate change because warmer air has the capacity to hold more water.

Intercomparison Project Phase 5 (CMIP5). The climate models in the CMIP5 rely on standard socioeconomic trajectories, known as Representative Concentration Pathways (RCPs), that describe different potential future greenhouse gas emission scenarios. RCPs are not forecasts or predictions but are plausible climate scenarios based on future energy sources, population growth, economic activities, and technological advancements over the course of the century. There are four RCP scenarios in the CMIP5: RCP2.6, RCP4.5, RCP6.0, and RCP8.5.

Following the Montana Climate Assessment, this primer presents information from the RCP4.5 and RCP8.5 scenarios. RCP4.5 is a stabilization scenario that assumes a peak in greenhouse gas emissions around 2040 followed by a decline, and expresses confidence that the global community will take action in the near future to reduce emissions. RCP8.5 is a business-as-usual scenario that assumes greenhouse gas emissions will steadily increase throughout the 21st century and expresses low confidence in the global community's ability to reduce emissions. Throughout this primer, RCP4.5 and RCP8.5 will be referred to as the "stabilization scenario" and the "business-as-usual scenario", respectively.

Current and Historical Conditions

Missoula County is located west of the Continental Divide, and as such its climate is heavily influenced by the weather patterns of the Pacific Northwest, with cooler summers, milder winters, and more year-round precipitation than central and eastern Montana. **Figure 3** and **Figure 4** compare seasonal average temperature and precipitation in Missoula County and Montana as a whole.[3] Note that while the City of Missoula receives an average of about 14 inches of precipitation per year, higher-elevation regions in the county receive much more, resulting in a county-wide average of nearly 30 inches per year.

[3] Unless stated otherwise, seasons are defined in this primer as winter (December-February), spring (March-May), summer (June-August), and fall (September-November).

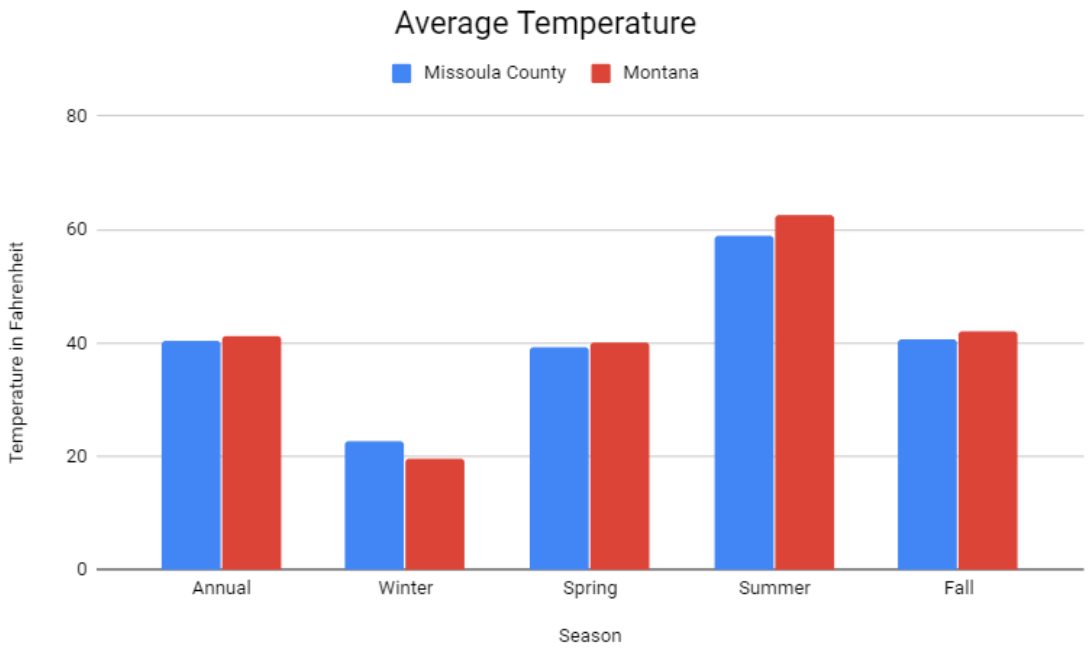

Figure 3. Comparison of Missoula County's and Montana's annual and seasonal average temperature. Data from NOAA Climate at a Glance tool for years 1901-2000. Averages include both daytime and nighttime temperatures.

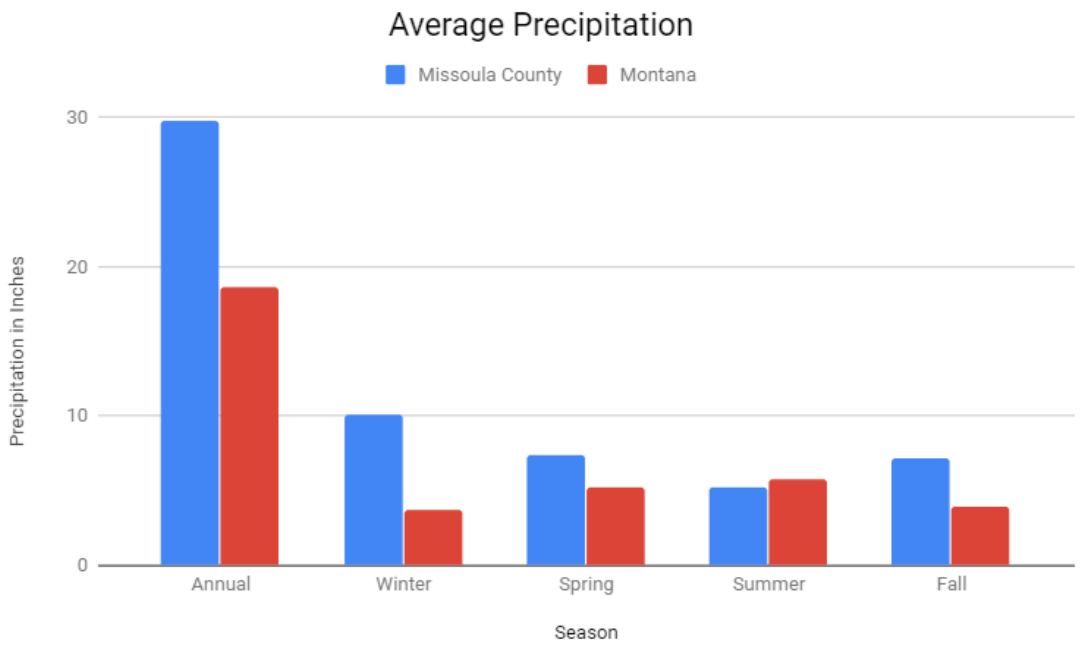

Figure 4. Comparison of Missoula County's and Montana's annual and seasonal average precipitation. Data from NOAA Climate at a Glance tool for years 1901-2000.

Since 1950, Montana's annual and seasonal average temperatures have been steadily increasing. From 1950-2015 northwestern Montana's average annual temperature increased by about 2.5°F, with the highest rate of warming occurring in the spring (Whitlock et al. 2017). During the same period, average annual precipitation in northwestern Montana decreased by about 3.8 inches, with most of that decline occurring during the winter season. This decreasing trend likely comes from an increased number of El Niño events, which are associated with warmer and drier winters, during this time period. The El Niño Southern Oscillation (ENSO) is a natural phenomenon and therefore it is likely that this declining precipitation trend is a part of the natural climate variability of the Pacific Northwest. For more information on ENSO and its relationship to Montana's climate, see Chapter 1 of the Montana Climate Assessment (Whitlock et al. 2017).

Rising average temperatures have been accompanied by changes in Montana's climate extremes. An analysis of climate extremes performed by the Montana Climate Assessment found a significant decrease in the number of days per year with intense cool temperatures and a significant increase in the number of days per year with intense warm temperatures. During the period 1951-2010, monthly minimum and maximum temperatures have increased by 5°F and 1.1°F, respectively. Throughout the state, the number of frost days (days with minimum temperatures below 32°F) has decreased by 12 days from 1951-2010, while the number of hot days (days with maximum temperatures exceeding 90°F) has increased by 11 days. These trends have contributed to an increase in the length of the growing season by 12 days since 1951 (Whitlock et al. 2017).

Future Climate Projections

Temperature

In both the stabilization and business-as-usual emission scenarios, temperatures are projected to continue increasing. By mid-century, Missoula County's average annual temperature is projected to increase by about 4°F in the stabilization scenario and 5°F in the business-as-usual scenario. By the end of the century, Missoula County's average annual temperature is projected to increase by about 5°F in the stabilization scenario and 8°F in the business-as-usual scenario. The greatest temperature increases are projected in July, August, and September. **Figure 5** shows the projected change in average annual and seasonal temperature by mid-century and the end of the century.

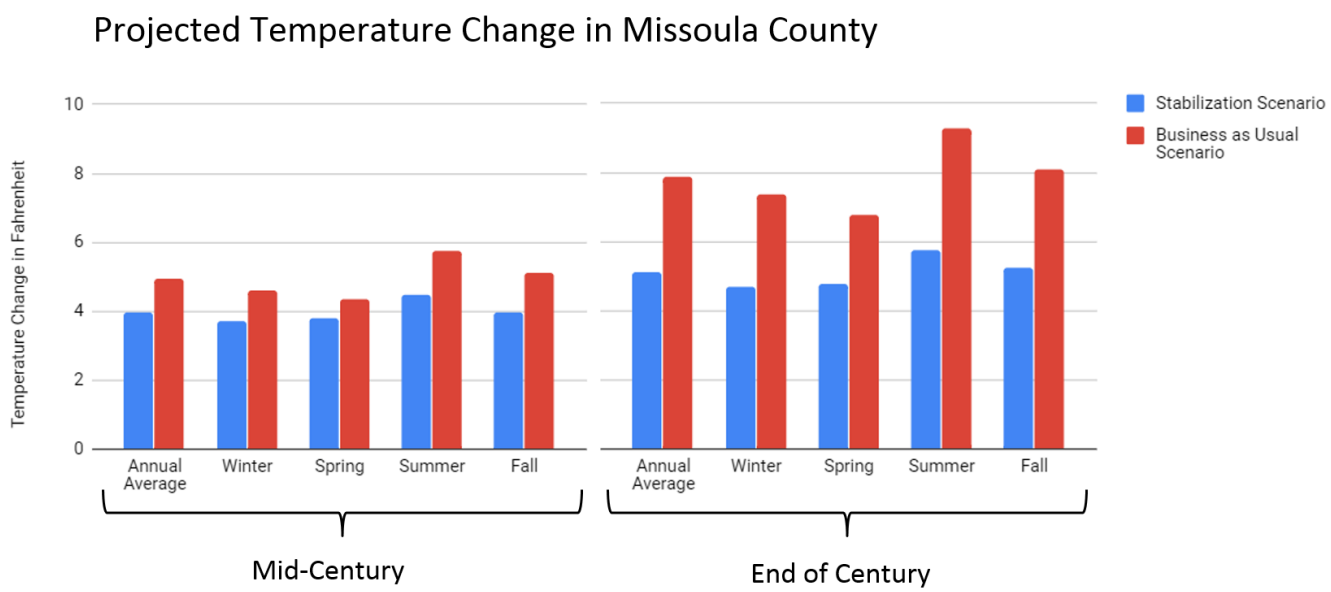

Figure 5. Projected change in annual and seasonal average temperature for Missoula County by mid-century and the end of the century. Data from Climate Explorer.

As temperatures rise, the average number of hot days (> 90°F) per year is projected to increase 12-20 days by the middle of the century and 18-39 days by the end of the century.[4] In contrast, the average number of frost days per year is projected to decrease 36-46 days by the middle of the century and 45-73 days by the end of the century.

Precipitation

Average annual precipitation for Missoula County is projected to increase by 2-3% by mid-century and by 3-6% by the end of the century. However, the change in precipitation is not expected to be uniform across all seasons. Winter and spring (and, to a lesser extent, fall) are expected to receive more precipitation, while summers are expected to be drier (**Figure 6**). This projection differs from the decrease in precipitation (especially winter precipitation) observed in Missoula County in recent decades. This difference is likely due to natural variability from the El Niño Southern Oscillation, as discussed above, and a time lag in the effect of anthropogenic warming on precipitation. While it takes many years to establish climate trends, recent changes in precipitation appear to align more closely with projections.

Warmer temperatures are likely to result in more precipitation falling as rain rather than snow in the western Montana, especially at low elevations (Whitlock et al. 2017).

[4] Ranges represent the difference between the stabilization and business as usual scenarios.

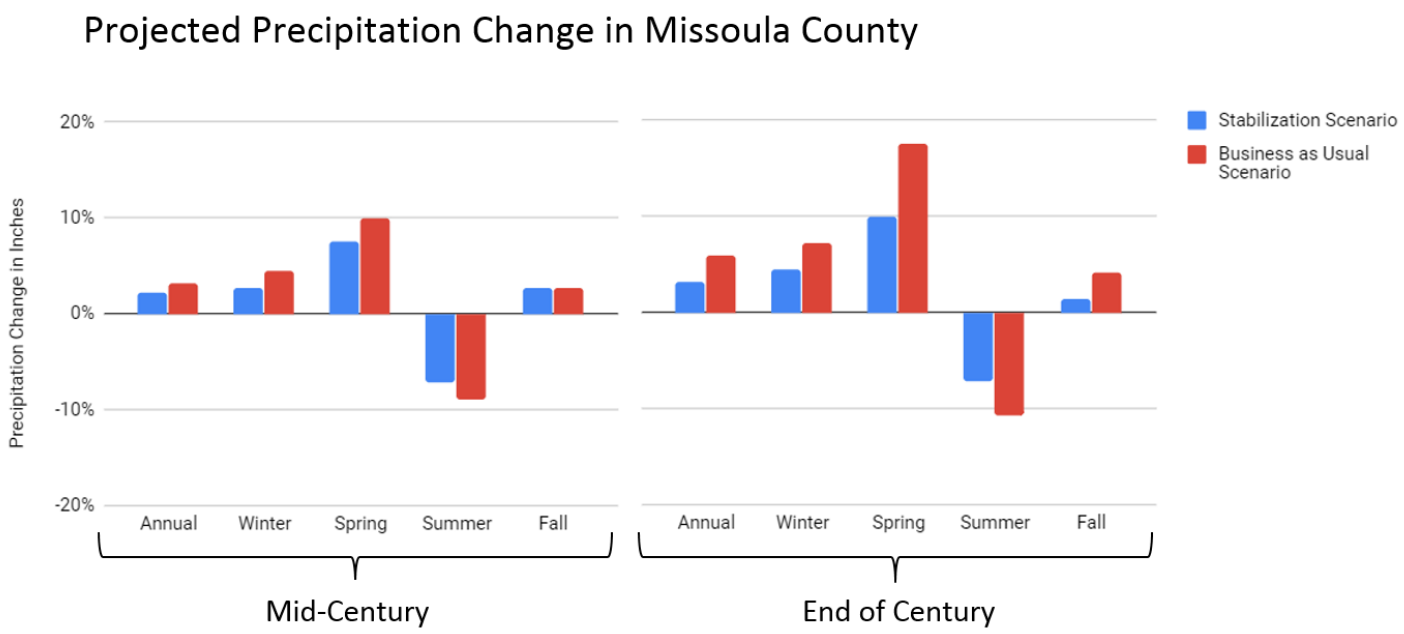

Figure 6. Projected changes in average seasonal precipitation for Missoula County by mid-century and the end of the century. Data from Climate Explorer.

Concluding Thoughts on Climate Projections

It's hard for statistics to paint a complete picture of what it will be like to live in Missoula County in 2050 or 2100. Luckily, we can draw on recent experience to help paint that picture. The summer of 2017 was significantly warmer and drier than the historical average; in northwest Montana, summer temperatures were 4.1°F higher than the average of the past 30 years, and summer precipitation was 2.4 inches less than the 30-year average. These conditions are similar to what projections suggest will be the new average in Missoula County by mid-century. It is likely no coincidence that 2017 was also one of the worst fire seasons ever recorded for Missoula County.

Also, **refer to the mid-century climate scenarios for Missoula County (pages 2-5)** for further illustrations of how climate change may impact the county over the next 30 years.

What Will Climate Change Mean for Missoula County?

The preceding chapter covers climate change projections for Missoula County: specifically, the temperature and precipitation changes we can expect in the coming decades. This chapter describes possible implications of those changes for the county's environment and natural systems, agriculture, cultural resources, human health, and economy. Background information is also included to provide context for the climate change discussion.

A selection of the impacts described in the following sections are also included in the three mid-century climate scenarios for Missoula County presented on pages 2-5.

Environment and Natural Systems

Water Systems

Background

Missoula County falls predominantly within the Clark Fork River Basin. The Clark Fork, which is the largest river in Montana by volume, is a snowmelt-dominated river that sees most of its annual streamflow delivered during a relatively brief period (April-July). The majority of snowpack in the Clark Fork River Basin occurs at relatively low elevations, below 8,000 ft (Whitlock et al. 2017).

The Clark Fork River and its tributaries are central to Missoula County's identity and to our economy. The river recharges the aquifer that supplies drinking water to the Missoula Valley, agricultural operations rely on water from the Clark Fork and other rivers and streams, and rivers are key to the county's recreation and tourism industries.

Snowpack

In recent decades, winter snowpack has decreased at low elevations in Missoula County. This decrease is caused by a combination of increasing winter temperatures and decreasing winter precipitation. At higher elevations, snowpack has decreased mainly from reduced winter precipitation (Mote et al. 2018); also see discussion in the Climate Change Projections chapter about the El Niño Southern Oscillation. In the future, lower elevations will be most impacted by the projected increase in temperature, resulting in a 30-40% decrease in snowpack by mid-century and in a higher elevation snowline. Some studies suggest that we could see an increase in snowpack at high elevations (above 6,500 ft); however, since a small fraction of Missoula County is so high, this potential increase is unlikely to offset the expected decrease in snowpack at lower elevations., By the end of the century increasing temperatures will likely reduce snowpack significantly across the county, even at high elevations.

Streamflow

The greatest impact of climate change on Missoula's water resources is likely to be earlier snowmelt and an earlier peak in spring runoff. Over the past half-century, spring runoff has

shifted at least a week earlier in the northern Rockies, and this trend is likely to continue as the climate continues to warm (Whitlock et al. 2017).

Earlier snowmelt and decreased summer precipitation are expected to reduce late-summer streamflows in Missoula County. A study of August flows in the Clark Fork River at St. Regis from 1929-2015 found that higher spring and summer temperatures and lower summer precipitation were associated with lower August streamflows (Whitlock et al. 2017). The projected decrease in August streamflows is important due to the high demand for water in late summer to support agriculture and river recreation.

Higher summer temperatures and lower streamflows will also contribute to increasing river temperatures, with potentially catastrophic impacts on some aquatic species (see page 29 for details) and on associated recreational industries.

Groundwater

In general, groundwater is "recharged" by the infiltration of precipitation and snowmelt through the soil as well as direct movement of water from surface streams, irrigation canals, and irrigated fields. The Clark Fork River is responsible for over 80% of the recharge of the Missoula aquifer (Miller 1991), making the aquifer susceptible to climatic changes. Warmer temperatures and a longer growing season will increase water lost to the atmosphere through evapotranspiration, which will reduce streamflow in the Clark Fork and thus decrease recharge of the Missoula aquifer.

While these vulnerabilities are serious, Missoula County is less vulnerable to climate impacts on its water supply than other parts of the state that rely more heavily on surface water. Aquifers store water underground where evaporative loss is minimal and water quality is better protected. This will help to buffer our water supply from some of the effects of climate change.

Flooding

Missoula County's rivers and streams experience regular flooding as a result of excess water from snowmelt and rainfall. Flooding can also be caused by ice jams, which are formed when pieces of floating ice accumulate and obstruct the stream, causing upstream flooding and the potential for flash flooding downstream when the ice jam gives way.

Missoula County has had six federal disaster declarations for flooding since 1974, including in 2018. Property damage from flooding events in the county between 1969 and 2011 exceeded $14 million. According to FEMA floodplain maps adopted by Missoula City and County in 2015, 1.8 percent of county land area lies within the 100-year flood hazard area, including 362 residences, 35 commercial, industrial and agricultural buildings, and 3 critical facilities (Missoula County Office of Emergency Management 2017).

The 2017 Update to the Missoula County Pre-Disaster Mitigation Plan summarizes flood protection measures that have been implemented in the county to date, including certified and uncertified levees, dikes, berms, and embankments (Missoula County Office of Emergency Management 2017). Missoula City and County generally require development within the designated floodplain to have its lowest floors two feet above the 100-year flood elevation. However, FEMA floodplain boundaries and projected 100-year flood elevations are based on 50-

year-old hydrologic and hydraulic analyses which do not account for the significant subsequent development that has occurred in the Clark Fork drainage, much less climate change projections.

There is considerable uncertainty regarding future flood risk due to climate change, since flood risk depends in part on specific storm characteristics that are difficult to accurately model (Whitlock et al. 2017). Throughout Montana's history, rain-on-snow events have caused the most severe and destructive floods. Some evidence suggests that warm and wet winter storms originating in the Pacific Ocean (a.k.a "atmospheric rivers") will become more severe in the future, likely bringing more rain-on-snow events to Missoula County (Warner, Mass, and Salathé 2015).

Extreme precipitation events (intense rain) are another common cause of flooding in Montana, and climate models project a slight increase in the frequency of days with more than 1 inch of rain in Montana by mid- to late-century (Whitlock et al. 2017). Other studies project even larger increases in the magnitude of Missoula County's most intense rain events (Prein et al. 2016).

Drought

Drought is a natural feature of Montana's climate, and there is considerable uncertainty about the impacts of climate change on long-term (multi-year) drought. Projections in the northern Rockies and Great Plains that focus only on precipitation suggest no increase in long-term drought frequency, while projections that include more variables, such as temperature and evapotranspiration, predict more droughts in the second half of the century. However, there is widespread agreement that climate change will result in more severe long-term droughts when and where they do occur (Whitlock et al. 2017).

Land Systems

Summary

Dominant land cover types in Missoula County include forest, woodland, and grassland systems. These forest and grassland systems provide the foundation for several important habitats in the county, and include four wilderness areas. Forests and grasslands provide crucial ecosystem services to both the wildlife and people of Missoula County. For example, forests can act as carbon sinks, help prevent erosion, and promote biodiversity (United States Forest Service 2016). These lands provide a home for a number of threatened and endangered species, such as the grizzly bear and the westslope cutthroat trout.

The projected changes in temperature, precipitation, and water systems in Missoula County, as described in previous chapters, will have far-reaching impacts on the county's ecosystems.

Missoula County Vegetation

Complete descriptions of the various ecological systems in Missoula County are available from the Montana Natural Heritage Program's Map Viewer at http://mtnhp.org/MapViewer/.

Forests

Nearly fifty percent of Missoula County is forested. However, the varied topography and climate of Missoula County means that these forests are not homogenous. Across the county, there are

numerous subsystems of forest that are adapted to the local climate and terrain**.** Depending on the environmental conditions of the area, forests in Missoula County range from conifer dominated systems comprised of Douglas-fir, ponderosa pine and western larch, to ecosystems that are primarily comprised of Engelmann spruce and subalpine fir (Montana Natural Heritage Program 2017d, [b] 2017). These forest systems provide a home to countless species of wildlife including several species of concern such as the Canada lynx and the grizzly bear. Embedded within the forests are riverine and riparian systems, home to fisheries and rich aquatic life.

Climate change will have both direct and indirect effects on the county's forests. Direct effects are the impacts of rising temperatures and changing precipitation patterns on trees. These effects and can be either positive or negative depending on tree species and on local factors like soil composition and water and nutrient availability. Overall net effects are likely to be negative, particularly in water limited areas (Whitlock et al. 2017). However, these direct effects are likely to be dwarfed by the indirect effects of increased fire risk and increased bark beetle outbreaks, as discussed in the following sections.

Wildfire

Wildfire is a naturally occurring phenomenon, and many ecosystems rely on fire at regular intervals to clear the forest floor, kill disease, and allow new plants to establish. Over the last century, the policy of attempting to suppress all wildfires has resulted in denser forests that, when they burn, do so much more intensely and destructively than they would have in the past. At the same time, expansion of the Wildland-Urban Interface (WUI) and increased development in the WUI put more people and structures at risk from wildfire.

The 2018 Community Wildfire Protection Plan for Missoula County defines the WUI as "Any area where the combination of human development and vegetation have a potential to result in negative impacts from wildfire on the community" (Mowery and Johnston 2018). As **Figure 7** shows, nearly all inhabited areas of the county (with the exception of the Missoula urban core) are in the WUI.

Missoula County is ranked in the 89th percentile among all counties in the western U.S. for wildfire risk to homes based on the amount of existing development in the WUI. The county is ranked in the 98th percentile for "potential risk" reflecting the large amount of undeveloped, forested private land bordering fire-prone public lands (Headwaters Economics 2018).

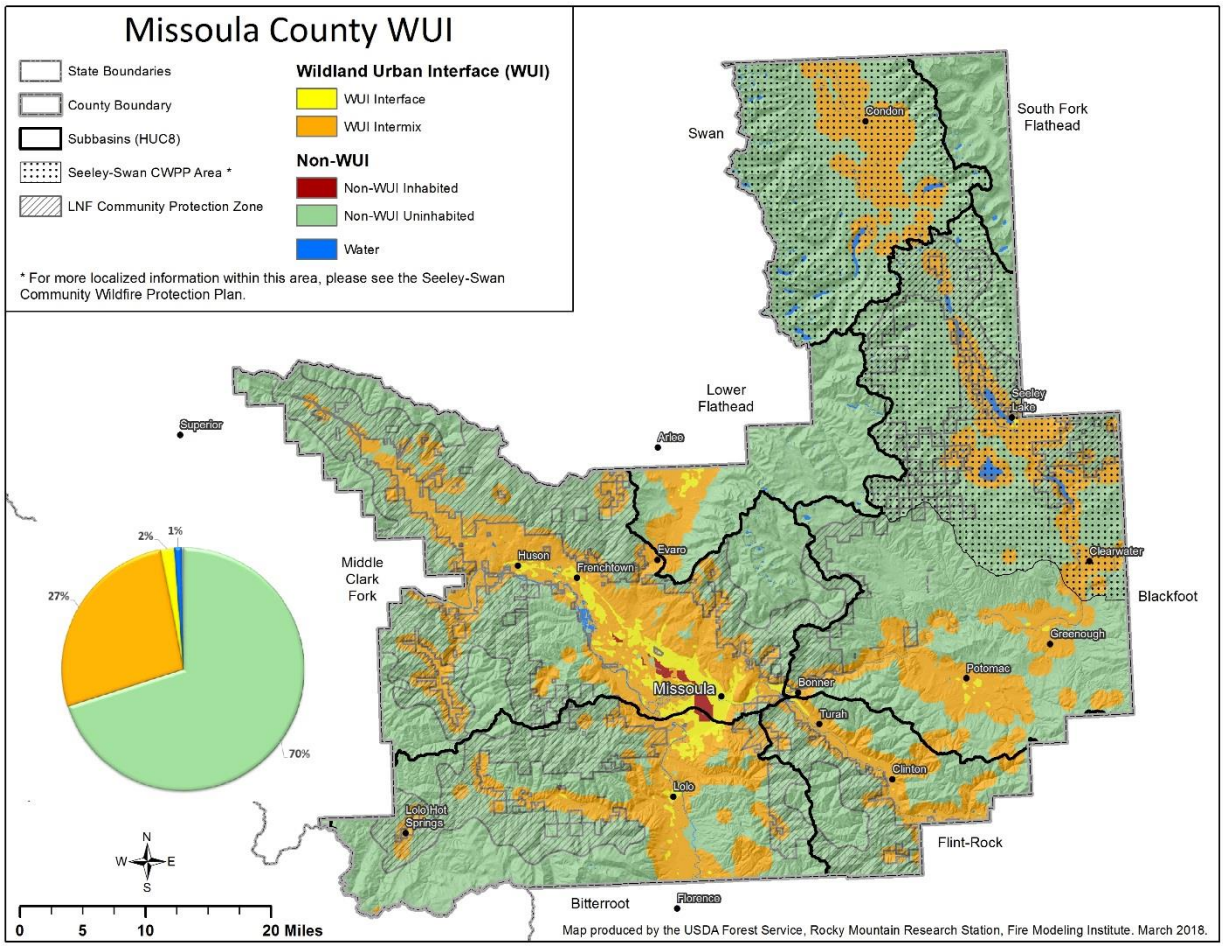

Figure 7. Wildland Urban Interface in Missoula County. Figure from Community Wildfire Protection Plan.

From 1998-2017, there were more than 3,000 recorded fires in Missoula County that burned 23% of county land area (Mowery and Johnston 2018).

An increase in the frequency and severity of wildfires is expected in the coming decades as a result of both climate change and increased forest density due to the past century of fire suppression (Whitlock et al. 2017). Historically, fire frequency and acreage burned is directly associated with increases in summer temperatures and decreases in summer precipitation (Holden et al. 2018; Whitlock et al. 2017). As Missoula County's climate warms and as summers become drier, wildfires are likely to increase in size and frequency and the fire season is likely to become longer.

This increase in the size and frequency of wildfires is expected not just in Missoula County, but across the western U.S. and Canada (Abatzoglou and Williams 2016). This is important to county residents and visitors because wildfire smoke travels to Missoula County from fires burning as far away as California and British Columbia. Wildfire smoke is a significant public health concern in Missoula County; see page 35 for details.

Bark Beetles

Almost every conifer in Missoula County, with the exception of larch, has an aggressive bark beetle species that attacks it. When periods are favorable, these beetles can increase in number and kill substantial numbers of trees. In recent decades, warmer temperatures caused by climate change have allowed native mountain pine beetle populations to proliferate across the west in lodgepole pine in what became the largest outbreak ever recorded, by a factor of ten (Meddens, Hicke, and Ferguson 2012). Warming temperatures also allowed the beetle to move up in elevation, killing over 1.5 million acres of whitebark pine and contributing to the recommendation to list it as an endangered species (Buotte et al. 2017). In recent years forest mortality as a result of the mountain pine beetle has declined, but other bark beetle populations are increasing: western pine beetle in ponderosa pine, fir engraver in grand fir, and Douglas-fir beetle in Douglas-fir. Beetle increases are directly tied to warming temperatures and increasing stress on trees (Six 2018). It is projected that increases in winter temperatures will lead to more frequent and severe outbreaks of mountain pine beetle and other bark beetle species (Millar, Stephenson, and Stephens 2007; Meddens, Hicke, and Ferguson 2012; Buotte et al. 2016, 2017). If continued large-scale bark beetle outbreaks occur, this, along with reduced regeneration due to climate change, is projected to lead to a substantial decline in the area covered by forest in Missoula County and Montana as a whole (Union of Concerned Scientists 2014).

Grasslands

Although they cover only 8.9% of Missoula County, grassland ecosystems are a common sight to Missoula County residents, as they border the City of Missoula and line the highways coming in and out of the town. Rough fescue, Idaho fescue, and bluebunch wheatgrass are by far the most dominant plant species of these ecosystems (Montana Natural Heritage Program 2017c). Grassland ecosystems are particularly vulnerable to invasive species. In some areas, invasives such as leafy spurge and spotted knapweed have completely taken over and forced out these native grasses (Montana Natural Heritage Program 2017c). As temperatures and CO_2 levels rise as a result of climate change, these invasive species may become more dominant and pose an even greater threat to Missoula County's grasslands (Whitlock et al. 2017).

Riparian and Wetland Areas

Riparian and wetland areas provide habitat for a diverse array of flora and fauna and are particularly important for Montana's native birds. Riparian corridors can span climatic gradients and could allow for connectivity and movement required for climate-induced range shifts. These natural areas can be extremely valuable within heavily modified landscapes like city centers (e.g., Clark Fork River and the City of Missoula). Forested riparian areas are cooler and more humid than immediately surrounding areas, providing refugia as temperatures warm (Krosby et al. 2014). Wetland areas near riparian corridors or in forested systems support a diverse taxa and provide resiliency against drought; unfortunately, these areas are often the most sensitive to higher temperatures.

Alpine Systems

Although accounting for just 1% of the land cover of Missoula County, alpine systems, including high elevation meadows and barren lands, are important environments. This area is above the "treeline" -- the elevation at which cold temperatures and long-lasting snowpack stop trees from growing -- and it provides habitat for unique species of plants and animals. As temperatures

warm and snowpack decreases, trees are able to grow at higher altitudes, causing alpine systems to shrink or disappear. As this habitat vanishes, species dependent upon it, like bighorn sheep and pika, are threatened.

Missoula County Important Lands

Missoula County contains parts of the Mission Mountain Wilderness, Bob Marshall Wilderness, and Selway-Bitterroot Wilderness and the entire Rattlesnake Wilderness. These wilderness areas can play key roles in protecting the county's natural systems from climate change because they are remote areas where natural processes can take place without human disturbance (Rasker 2011a). However, the lack of human involvement in wilderness areas has also allowed some invasive species to thrive in Montana's wilderness (Tempel, Cilimburg, and Wright 2004). As climate change facilitates the migration of invasive plant and animal species into these remote areas, it is possible that they will begin to disturb these once pristine systems.

Historically, wilderness areas have been thought of as places where natural processes should be left to their own devices without any human intervention (Stephenson and Millar 2014). However, as climate change drives shifts in plant and animal populations, the wilderness areas of Missoula County may become fundamentally different places than they have been in the past. Stephenson and Millar suggest that as the effects of climate change on wilderness areas intensify, we have four options: restraint (leave some places alone), resilience (enhance ecosystem's ability to absorb a stress without shifting into an entirely new state, such as from forest to meadow), resistance (near-term actions that buy time), and realignment (long-term adaptation, often including facilitated actions like assisted migration). Resiliency actions might include controlling selected non-native invasive species or thinning forests. Regardless of which option is chosen, climate change will undoubtedly alter the wilderness areas of Missoula County.

In addition to these wilderness areas, there are many other locations within Missoula County that wildlife and natural systems depend on. Some areas are key corridors that link large protected areas crucial for species movement (Belote et al 2016). In the 2015 Montana Wildlife Action Plan, three areas within Missoula County were cited as key habitats for wildlife.

Seeley-Gold Creek Area

The Seeley-Gold Creek area in the northwestern corner of Missoula County is a critical habitat for several species of concern including the Canada lynx, grizzly bear, and the great blue heron. Because of its location between the Mission Mountain, Bob Marshall, and Rattlesnake Wilderness areas, this area also provides connectivity for these species of concern to travel between wilderness areas (Montana Fish, Wildlife and Parks 2015).

Bitterroot-Clark Fork Riparian Corridor

The Bitterroot-Clark Fork Riparian Corridor is another critical area for Missoula County's wildlife. The corridor is a key breeding habitat for a number of Montana's bird species including some species of concern such as the Great Blue Heron. Additionally, the corridor serves as a migration path for migrant species of birds (Montana Fish, Wildlife and Parks 2015). A portion of this area west of Missoula is an Audubon designated "Important Bird Area" (National Audubon Society n.d.) considered for both the riparian and surrounding grassland habitats.

Fish Creek Area

In addition to these crucial bird and mammal habitats, riparian areas also play an important role for the wildlife of Missoula County. Although riparian areas only comprise 7.6% of the County's total land cover, 95% of the wildlife in Missoula County depend on these riparian habitats (Rasker, 2011). One such habitat is the Fish Creek area in the western portion of the county. The Fish Creek area is a key habitat for bull trout, a threatened species, and westslope cutthroat trout, a species of concern (Montana Fish, Wildlife and Parks 2015; Montana Natural Heritage Program and Montana Fish, Wildlife and Parks, n.d.).

Because of their unique locations, riparian systems, and vegetation cover, these three regions provide countless species with a niche habitat that can be found nowhere else in the county. Unfortunately, the 2015 Montana Wildlife Action Plan projects that all three of these areas could be adversely affected by climate change and human development in the coming century. Specifically, logging operations, housing development, and increased temperatures as a result of climate change all have the potential to fragment plant and animal habitats, reduce biodiversity of native plant species, and facilitate the spread of invasive species (Montana Fish Wildlife and Parks, n.d.; Ortega and Pearson 2013; Williams et al. 2007).

Important Species of Climate Concern

Missoula County is home to countless plant and animal species, of which 94 animals and 66 plants are listed as Species of Concern (SOC) by the Montana Natural Heritage Program and Montana Fish, Wildlife and Parks. In Montana, SOC are defined as "native Montana animals or plants that are considered 'at risk' due to declining population trends, threats to their habitats, and/or restricted distribution" (Montana Natural Heritage Program 2016).[5]

No comprehensive statewide evaluation has been done of the impacts of climate change on Species of Concern or other plants and animals. However, NatureServe provides a climate change vulnerability index that can be filtered for species of interest (NatureServe n.d.); and the National Audubon Society provides robust data and reporting on birds and climate change (National Audubon Society 2015).

While climate change is likely to affect many animal species in Missoula County, here we highlight two mammal species listed as threatened under the Endangered Species Act and likely to be particularly vulnerable to climate change: the grizzly bear and the Canada lynx. We also highlight two native fish species negatively impacted by warmer water temperatures: westslope cutthroat trout and bull trout.

Grizzly Bear

The Grizzly bear is perhaps one of the most iconic species of Missoula County. In the county, the grizzly bear can routinely be found in the Mission Mountain Wilderness, the Bob Marshall Wilderness, and the Flathead Reservation (Montana Natural Heritage Program 2016, 2018). While increased temperatures don't pose a direct threat to the grizzly bear, they do have a number of indirect consequences for bear populations. For example, rising temperatures have allowed mountain pine beetle populations to increase significantly, which has led to increased

[5] A full list of Missoula County Species of Concern and accompanying "field guide" can be found at http://mtnhp.org/SpeciesSnapshot/?Vector=COUNTY%7CMissoula.

whitebark pine mortality, reducing the availability of whitebark pine nuts which are an important food source for grizzly bears (Whitlock et al. 2017; Costello et al. 2015). While not all grizzly bear experts concur, Costello et al. found in their 2015 study that some grizzlies have adapted to decreased whitebark pine nut availability by finding alternative food sources.

Canada Lynx

Added to the endangered species list as a threatened species in 2000, the Canada lynx is strongly associated with moist, cool, boreal spruce-fir forests. Lynx live predominantly in areas that receive relatively uniform, deep snow amounts, and in Missoula County most lynx sightings occur in the Seeley-Swan area (Montana Natural Heritage Program and Montana Fish, Wildlife and Parks n.d.). Recent modeling suggests that climate change is likely to impact lynx (United States Fish and Wildlife Service 2013). The Canada lynx is at risk from warming winters during which there is a decrease in the length of time snow remains on the ground. Their primary food source, the snowshoe hare, relies on camouflage, growing a new coat twice a year (white in the fall and brown in the spring). A decline in the number of days with snow-covered ground can result in mismatches between hares' camouflage and their surroundings. Declines in hare can influence lynx population dynamics, as the two are closely tied (Mills et al. 2013).

Westslope Cutthroat Trout

The westslope cutthroat trout (WCTT) is native to Missoula County and is classified as Montana's state fish (Montana Natural Heritage Program and Montana Fish, Wildlife and Parks, n.d.). Climate change affects the WCTT population in three primary ways: by increasing water temperatures, increasing the frequency of winter flooding of WCTT habitat, and increasing the frequency of wildfires, which degrade WCTT habitat (Williams et al. 2009). In the Clark Fork River Basin, of which Missoula County is part, increased water temperatures and fire frequency are projected to have relatively little impact on the WCTT population. Winter flooding caused by warming winter temperatures, on the other hand, is projected to have a significant impact on WCTT populations (Williams et al. 2007). Additionally, invasive fish species have led to a decrease in WCTT populations. Some non-native fish are able to outcompete WCTT for food and force a decline in their population. Land managers suggest decreasing habitat fragmentation of the WCTT and removing non-native species from WCTT habitats to preserve their dwindling population (Williams et al. 2007; Montana Natural Heritage Program and Montana Fish, Wildlife and Parks, n.d.).

Bull Trout

The bull trout is another iconic fish species of Missoula County that is affected by climate change. The bull trout requires cold water for spawning and survival (Montana Fish Wildlife and Parks, n.d.). As climate change leads to generally warmer river temperatures, this means that the bull trout will need to either adapt to warmer temperatures or move upstream to cooler water, shrinking the size of its habitat. Climate change compounds other issues that affect bull trout populations, including land use changes, invasive species, and dams in bull trout habitat. Insertion of dams into bull trout habitat can lead to habitat fragmentation and increased sedimentation in spawning grounds. Increased sedimentation can prevent bull trout eggs from hatching and block the small nooks and crannies that newly hatched bull trout rely on to hide from predators while they are young (Montana Fish Wildlife and Parks, n.d.).

Invasive Species

Missoula County is home to a wide variety of invasive and non-native species. These include plant, invertebrate and vertebrate species impacting both terrestrial and aquatic systems. While current infestations are limited to mostly terrestrial and aquatic invasive plant species, there are a variety of other invasive species that have the potential to spread and further impact the county. The total damage and control costs of invasive species for the country is estimated at about $120 billion annually (Pimentel 2005).

Terrestrial invasive plants such as leafy spurge and spotted knapweed, along with annual grasses such as cheatgrass and ventenata, are the most widespread and established invasive species impacting Missoula County. Cheatgrass infests over 100 million acres in the Western U.S., and spotted knapweed is estimated to infest 2-5 million acres in Montana alone (Duncan et al. 2017). Terrestrial invasive plant species thrive in areas that have been recently disturbed. As a result, as climate change leads to increased rates of forest fire and as humans continue to develop and disturb natural landscapes, these species will continue to thrive and expand (Rasker 2011a; Whitlock et al. 2017). Prevention, survey and monitoring efforts as well managing for diverse plant communities can help curtail their spread, and local wilderness areas may serve as key locations due to their greater resilience to the spread of these species.

While not currently found in Missoula County (or anywhere in the Columbia River Basin), aquatic invasive species such as zebra and quagga mussels can cause significant economic and environmental damage due to their ability to rapidly reproduce and attach themselves to any hard substrate in a waterbody. They remove nutrients, collapse entire food webs, reduce fish populations and devastate fisheries. Recreational boaters experience significant equipment damage, and they rapidly clog hydroelectric facilities, freshwater aqueducts, municipal and irrigation water systems and other water infrastructure. Once established, there is no effective method to eradicate them. The Pacific NorthWest Economic Region estimates that zebra and quagga mussels could cost the Columbia River Basin more than $500 million annually.

Invasive forest pests such as the emerald ash borer pose a serious threat to both native and urban forests, causing ecological damage to private and public lands and economic impacts to private landowners, municipalities, and nursery and forest product industries. While not yet found in Montana, the emerald ash borer has spread rapidly into neighboring states and provinces.

Ecological Processes

Warming temperatures have the potential to alter basic phenological processes resulting in mismatches between mutualistic partners or predator/prey relationships. For example, this might include:

- The timing of host plant flowering and pollinator activity resulting in lack of pollination or reduced food availability;
- Early plant growth outside of optimal windows for foraging;
- Camouflage mismatch: snowshoe hares or white-tailed ptarmigan out of sync with winter snowpack;
- Insect abundance out of sync with insectivorous bird breeding cycles; and,
- Drought, floods, extreme weather, and heat affecting health, reproductive success, disease, and mortality in animals and plants just as they do in humans.

Economy

Agriculture

Background

Agriculture plays a modest but important role in Missoula County's economy, and makes a major contribution to the county's culture and quality of life. Large and small farms, ranches, teaching farms, urban community gardens, and personal garden plots dot the county's landscape. In addition to agricultural production, such lands provide open space, scenic vistas and in some cases, bird and wildlife habitat.

Missoula has a thriving local food scene including several weekly farmers' markets, farm stands, Farm to College and Farm to School programs, community supported agriculture (crop share) programs, and a food distribution hub connecting more than 40 farms to restaurants, schools, and other institutions. The Western Montana Growers Cooperative also provides a connection between interested buyers and agriculture producers, with a diverse array of more than 50 farmers and ranchers extending beyond Missoula County. Overall, there is growing interest in localizing the food system and shortening the distance from farm to plate in order to reduce our food footprint, support the local economy, and feed our residents from within our foodshed. Both the City and County Growth Policies include the preservation of agricultural land and local food production among their goals and objectives.

Despite the value that the community places on local agriculture, there is significant development pressure on agricultural land in and near the Missoula urban area. The Community Food and Agriculture Coalition reports that nearly 29,000 acres of farm and ranchland was converted from agricultural to non-agricultural use between 1986 and 2010, and that roughly 80% of the lands containing the best agricultural soils have been subdivided into parcels less than 40 acres (Hubbard and Hassanein 2010).

Between 1974 and 2012 the total number of acres in agricultural production in the county decreased about 6%. While the number of farms in the county more than doubled during that period, from 310 to 637, the size of the average farm decreased from 845 to 388 acres. Today nearly half of farms in the county sell less than $1,000 worth of agricultural products per year. This suggests that an increasing number of "farms" in the county are rural residences with agriculture playing a secondary role on the property (Hubbard and Hassanein 2010).

In total, farm employment accounts for less than 1% of total jobs in Missoula County. The largest agricultural sales in the county are cattle and calves ($8.1 million), nursery and greenhouse sales ($1.9 million), and crops and hay ($1.5 million)(Missoula County 2016). Alfalfa is the largest crop in the county by acreage planted (about 12,000 acres in 2017) followed by non-alfalfa hay (4,400 acres), wheat (900 acres) and barley (300 acres)(United States Department of Agriculture, National Agricultural Statistics Service 2018). The majority of Missoula County crop production is irrigated, including about 90% of alfalfa production. Profit margins for Missoula County farmers are slim; overall net farm income (receipts minus expenses) has been negative nearly every year for the past several decades (Headwaters Economics 2018).

Agriculture and Climate Change

Predicting agricultural conditions in a changing climate is difficult and warrants more region-specific research. Numerous factors will play a role. Warmer weather, and specifically a later fall freeze and earlier spring thaw, will increase the length of the growing season. However, less summer precipitation will reduce water available for plant growth, and farmers could also face more intense flooding and drought, in particular late-summer drought; consequent volatility of access to irrigation; increased growth of invasive species; threatened pollinators; and more difficult or novel weed and pest control. Ranchlands in particular are challenged by invasive weeds (cheatgrass, leafy spurge, thistle, spotted knapweed, etc.), and these may increase with climate change.

Preliminary modeling by researchers at the University of Montana as part of a project on the Hydro-Economics of Agricultural Production suggests that the county's agricultural sector (in particular, production of the three largest crops in the county: alfalfa/hay, wheat, and barley) is likely to be relatively resilient to the projected reduction in summer precipitation. In other words, total production of these crops in the county is not likely to change significantly in response to a decline in precipitation. There are two reasons for this: first, the prevalence of irrigation in the county, since irrigated crops are less sensitive to changes in precipitation; and second, the fact that thus far water has not been a limiting factor for agriculture in the county.

In fact, the model suggests that even if the amount of irrigation water available were reduced significantly (e.g., due to reduced streamflow), there would likely be modest impacts on crop acreage, since there is significant potential to improve irrigation efficiency. However, a reduction in irrigation at farms would have impacts beyond the agricultural sector, since excess irrigation water recharges the groundwater system and contributes to wetlands that support numerous plant and animal species. It is also important to note that this modeling does not take into account the effects of climate change on invasive weed growth and plant disease, and possible consequent impacts on crop production.

Of course, water supplies are not endless, and at some point declines in precipitation and in the availability of irrigation water would make water a limiting factor for agricultural production in the county. This is especially true considering that Missoula County is downstream of counties with high agricultural water use. If farmers in upstream counties increase irrigation to compensate for declining growing season precipitation, this will increase the risk that water becomes limiting in Missoula County during drought. At that point, farmers are likely to prioritize irrigation for alfalfa at the expense of wheat and barley. Moreover, as water availability declines and agricultural water use intensifies, conflict with other water users (including urban users, rural residences, and ecosystems) are likely to emerge.

There are several resources in the state to help farmers adapt to climate change; for example, the Montana State University Extension Climate Science Program and the One Montana Water, Agriculture and Climate Program.

Recreation and Tourism

Missoula County's natural beauty and recreational opportunities are important to the county's economy. Outdoor activities such as hiking, mountain biking, fishing, and snow sports contribute much more to the county's economy than expenditures on gear and lift tickets; they are major factors in the high quality of life that draws residents and businesses to the area. More than 20% of Missoula County jobs are related to travel and tourism (Headwaters Economics 2018), much of it driven by these recreational opportunities.

All of these outdoor activities will be affected by a changing climate. For example, the ski industry, including Snowbowl Resort near Missoula, will likely face reduced snowpack, shorter ski seasons, and closure of low-elevation ski terrain (Rasker 2011b).

As for fishing, several trout species are at risk from climate change (see page 29). Higher river temperatures will lead to more frequent and longer-lasting "hoot owl" fishing restrictions, which prohibit fishing during certain hours of the day in order to minimize stress on trout when water temperatures are high.

Increased wildfires and wildfire smoke also have significant implications for tourism and recreation. A 2015 study of the impact of climate change on Montana's outdoor economy (Power and Power 2015) estimated that visitation to Montana's two national parks (Yellowstone and Glacier) will decline by one-third as a result of increased wildfires and smoke. Because many visitors to the state pass through Missoula en route to one or both of the national parks, this decline will impact the county's economy. Overall, the 2015 study estimates that 10,922 jobs will be lost in the recreation and tourism industry statewide as a result of declines in national park visitation, wildlife watching and sightseeing, hunting, sport fishing, and snow sports. Missoula County is likely to bear a significant fraction of these losses.

It is worth noting that the impact of climate change on tourism in Missoula County will also be affected by the relative climate impacts on outdoor recreational opportunities elsewhere in the country.

Sustainable Economic Development

If we are to avoid the worst impacts of climate change, the global economy must transition rapidly away from fossil fuels. According to the Intergovernmental Panel on Climate Change, we must eliminate fossil fuel consumption almost entirely within 30 years. Renewable energy is already the fastest-growing energy sector worldwide, due in part to the rapidly decreasing costs of renewable energy technologies; but a greatly accelerated growth rate will be required to achieve this target.

This unprecedented economic transition presents tremendous opportunities for businesses in sectors like renewable energy, sustainable transportation, and waste reduction. To the extent that Missoula County is able to attract and nurture such businesses, we may be able to buffer some of the negative economic impacts of climate change in the county.

Cultural Resources

Missoula County is home to current and aboriginal lands of the Confederated Salish and Kootenai Tribes (CSKT). Before European settlement, the Salish, Kootenai, and Pend d'Oreille peoples seasonally resided in the Missoula and Bitterroot valleys for the collection of camas and bitterroot plants, fishing, and big game hunting. Non-native settlers arrived in the region in the early 19th century and began changing land use from resource collection and agroforestry to farm and ranch lands (Bobbitt 2015). Today, 5.6% of Missoula County falls within the Flathead Indian Reservation. Because of their current and historical connection to the lands of Missoula County, the CSKT are an important stakeholder for climate change preparedness and adaptation planning.

As a sovereign nation, the Tribes have taken the noteworthy step of creating their own climate readiness plan. Their findings, priorities, and future plans can be found in the CSKT Climate Change Strategic Plan (Confederated Salish and Kootenai Tribes 2013). The CSKT plan uniquely combines scientific research on the effects of climate change with traditional ecological knowledge of the region through the use of elder interviews. For example, elders understood the decreasing intensity of winter cold by noting changes in natural systems like snowpack and beetle infestations, and also its effect on cultural traditions like the timing of various hunting and gathering subsistence practices. In his forward to the strategic plan, former Council Chairman Joe Durglo writes, "Our survival is woven together with the land." Changes in climate, which the Tribes are already experiencing, threaten a way of life that has existed since time immemorial. The Tribes are committed to mitigating and adapting to these changes in order to preserve their natural resources, livelihoods, health, and cultural practices.

Human Health

Climate change is affecting human health across the globe, and Missoula County is no exception. Higher temperatures, poor air quality from wildfire smoke, and extreme events like flooding and drought will increasingly contribute to health problems including cardiovascular and respiratory disease, heat-related illness, water- and vector-borne disease, and mental health issues. Certain populations within Missoula County are more vulnerable to these health problems, including infants and children, older adults, people with existing respiratory or cardiovascular diseases, outdoor workers, and people of low socioeconomic status. It's worth noting that non-humans, from our pets to our wildlife, may also be affected by some of these health problems.

The Missoula City-County Health Department has a key role to play in preparing for and responding to the health impacts of climate change, and is currently working to develop a Climate Change Adaptation Plan following the CDC's Building Resilience Against Climate Effects (BRACE) Framework (Centers for Disease Control and Prevention 2015). A draft version of the Missoula City-County Health Department Climate Change Adaptation Plan (Farr 2018) is referenced throughout this chapter.

Health Services

Missoula County serves as the medical hub for the region and includes two hospitals (Providence St. Patrick Hospital and Community Medical Center) as well as a federally-qualified health

center that provides health care on a sliding fee scale (Partnership Health Center), and the nonprofit Missoula Urban Indian Health Center. Most health services are located in the Missoula urban area, meaning that residents of some rural parts of the county have to travel significant distances to access health care.

The number of Missoula County residents without health insurance has declined sharply in recent years, from 21 percent in 2013 to 7 percent in 2016, thanks to the Affordable Care Act and expansion of the Medicaid program (Missoula City-County Health Department 2017a).

The 2017 Community Health Assessment developed by the Missoula City-County Health Department includes the following findings relevant to this discussion (Missoula City-County Health Department 2017a).

- Aging population: The percent of the Missoula County population that is 60 or older is projected to increase 54 percent from 2015 to 2040, with the fastest growth among those 85 and older.
- The top two leading causes of death in Missoula County are the same as they are nationwide: cancer and heart disease. However, death by suicide is more than twice as common in Missoula County as it is nationwide.
- Native Americans in Montana have a significantly shorter life expectancy and higher suicide rate than white residents.

The following sections summarize the projected human health impacts associated with climate change in the county.

Air Quality

As Montana's climate warms and summers become drier, wildfires are likely to increase in frequency and intensity over the course of the coming decades. More wildfires in Montana and the west, and a longer wildfire season, mean more days of unhealthy air quality for Missoula County residents. Most Missoula County residents live in mountain valleys, and the nature of the topography increases residents' exposure to harmful pollution. In mountainous areas, cold air flows downhill and pools in valley floors every night, creating a temperature inversion that traps air pollutants near ground level in a layer of cold of air. The pollutants can't leave the area until the cold layer of air warms back up. This becomes particularly problematic when nearby fires send intense amounts of smoke into the mountain valleys - trapped smoke can quickly create unhealthy conditions that last for hours or days.

Researchers (Liu et al. 2016) have created a metric called "Fire Smoke Risk Index" based on a combination of the number, intensity, and length of smoky periods per year. **Figure 8** shows the Fire Smoke Risk Index by county in the western US in the recent past (panel a) and projected for midcentury (panel b). Fire Smoke Risk Index in Missoula County is projected to increase from Level 4 to Level 5 (the highest risk) during that time period, meaning more frequent and longer periods of poor air quality.

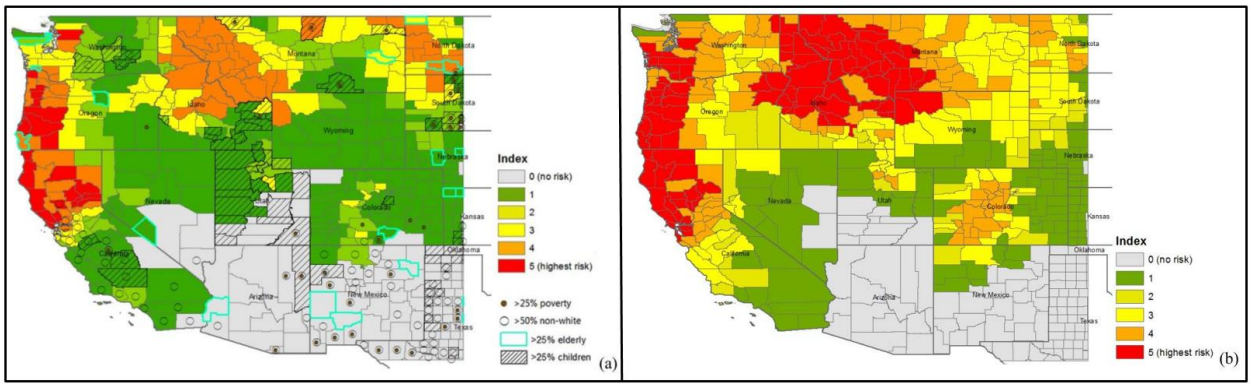

Figure 8. Fire Smoke Risk Index during fire seasons (May-October). Panel (a) is for present day (2004-2009) and panel (b) is for future (2046-2051) under climate change. Figure from Liu et al. (2016).

Studies have found strong associations between exposure to wildfire smoke and worsening of respiratory diseases like asthma and chronic obstructive pulmonary disease (COPD), as well as increased incidence of respiratory infections like bronchitis and pneumonia. Some studies have also found associations between wildfire smoke and cardiovascular problems like heart attacks and strokes (Reid et al. 2016). Infants and children, older adults, people with existing respiratory or cardiovascular diseases, and outdoor workers are particularly vulnerable to wildfire smoke. Children are especially vulnerable because their lungs are still developing and because they breathe more air per pound of body weight than adults do.

The National Ambient Air Quality Standard for $PM_{2.5}$ (particulate matter 2.5 microns in diameter and smaller) is 35 micrograms per cubic meter of air ($\mu g/m^3$) averaged over a 24-hour period. The U.S. EPA considers $PM_{2.5}$ levels above 35 $\mu g/m^3$ averaged over 24 hours to be unhealthy for sensitive groups, and levels above 250 $\mu g/m^3$ to be hazardous to human health. In 2017, Missoula County's worst wildfire smoke season on record, Seeley Lake residents experienced 18 days of hazardous air quality with 24-hour averages ranging from 252 $\mu g/m^3$ to 642 $\mu g/m^3$. They experienced 35 mornings with hourly $PM_{2.5}$ concentrations well above 250 $\mu g/m^3$, with hourly concentrations frequently ranging from 300-800 $\mu g/m^3$. Twenty times during that period, the hourly $PM_{2.5}$ levels exceeded 1,000 $\mu g/m^3$, which is the highest level the county's air quality monitors can measure. In August 2017, the Missoula City-County Public Health Department took the unprecedented step of recommending evacuation for the entire town of Seeley Lake due to hazardous air quality (Missoula City-County Health Department 2017b).

A study of more than 1 million emergency room visits in California found a spike in ER visits for heart attack and stroke, as well as breathing problems, during periods of dense wildfire smoke. For adults age 65 and older, the rate of ER visits for heart attack increased 42 percent during periods of dense smoke (Wettstein et al. 2018). In Missoula and Powell counties, the number of respiratory-related emergency room visits more than doubled during the 2017 wildfire season, jumping to 378 from 163 the year before (Saks 2018).

Temperature and Extreme Heat

Missoula County is getting hotter. By midcentury, the county is projected to experience 12-20 more hot days (maximum temperature greater than 90 degrees Fahrenheit) per year, and average

summer temperatures are projected to increase by 4-6 degrees (see page 18 for details). Higher summer temperatures and more days of extreme heat increase the risk of heat-related illness for Missoula County residents.

Heat-related illnesses, including heat exhaustion and heat stroke, occur when the body is exposed to extreme heat and becomes unable to cool itself, resulting in a rapid rise in body temperature that can lead in severe cases to death or permanent disability (Centers for Disease Control and Prevention 2016). Dehydration is also closely associated with heat exposure. Young children, older adults, people with chronic diseases, people who work outdoors, and people without access to cool areas, fans, or air conditioning are at the greatest risk of heat-related illness and dehydration.

In Missoula County, there were six deaths directly attributed to heat exposure in the decade 2001-2010, and six additional deaths in which heat exposure was a contributing factor. Overall, 198 individuals were admitted to Missoula County hospitals for heat-related illness during that decade (Farr 2018).

The combination of heat and wildfire smoke is particularly challenging. During wildfire season, air quality in the Missoula and Seeley Lake valleys is often worse at night due to temperature inversions, meaning that residents without air conditioning must choose between opening their windows at night to sleep in cool (but smoky) air, or leaving their windows shut and sleeping in the accumulated heat from the day.

Longer, warmer summers are also likely to result in Missoula County residents spending more time outdoors, increasing the risk of skin cancer. Montana already has higher than the national average rate of skin cancers (Farr 2018).

Waterborne Disease

Temperature, heavy rainfall, and flooding are expected to increase with climate change, creating a more suitable environment for many pathogens. Pathogens that cause diarrhea are of particular concern given that globally, diarrhea is the second leading cause of death among young children. In a critical review of 141 studies, researchers found positive relationships between diarrheal disease and temperature, heavy rainfall, and flooding in both developed and developing countries, including the United States (Levy et al. 2016). Water treatment systems, flood-ready infrastructure, and sanitation behavior all influence the risk of diarrheal disease as well.

In 2015, seventy-five cases of waterborne diseases were reported in Missoula County, including campylobacteriosis, cryptosporidiosis, giardiasis, and salmonellosis (Farr 2018).

Harmful algal blooms are another source of waterborne disease. Cyanotoxins are a byproduct of cyanobacteria, which thrive in warmer water and are likely to become more prevalent as global temperatures rise. Cyanotoxins can be toxic to the human nervous system, liver, and skin, and can kill fish, mammals, and birds. EPA sampling in 2007 found that 10 of 45 lakes sampled in Montana are at high risk of exposure to cyanotoxins based on cyanobacteria cell count (United States Environmental Protection Agency 2018).

Vector-borne Disease

Vector-borne diseases are caused by parasites that are transmitted to humans by insects such as ticks or mosquitos. In Montana, tick-borne diseases include Rocky Mountain spotted fever, tick-borne relapsing fever, Colorado tick fever, and tularemia. West Nile virus is the only mosquito-borne illness that has been diagnosed as locally acquired in Montana (Farr 2018). While all of these diseases remain relatively rare in Montana, their incidence may increase with increasing temperatures. In addition, other vector-borne diseases such as lyme disease, malaria, Zika virus, and dengue fever are likely to expand to previously unaffected areas as a result of climate change.

Flooding and Drought

Many of the health impacts discussed above are associated with increased flooding or drought; for example, poor air quality is associated with wildfires that are more likely during periods of drought, and water- and vector-borne diseases are exacerbated by flooding. Floods and droughts also have direct health impacts. The health risks of floods include drowning and injury, in addition to illness associated with contaminated water. Floods often disproportionately affect people of lower socioeconomic status.

There are also widespread health risks that stem from drought, and in any given community these impacts may vary. Reduced air quality, compromised food and nutrition, water related disease, airborne and dust-related disease, vector-borne disease, and mental health impacts can all emerge from or be exacerbated by drought (Stanke et al. 2013). However, more research is needed to understand the health effects of drought specific to Missoula County.

Mental Health

Climate change is projected to increase the frequency of extreme weather events and natural disasters. According to the American Public Health Association, 25-50 percent of people exposed to an extreme weather event are at risk of adverse mental health effects such as anxiety, depression, post-traumatic stress disorder (PTSD), and suicide. Studies found that 49 percent of the survivors of Hurricane Katrina developed an anxiety or mood disorder, and 1 in 6 developed PTSD (American Public Health Association 2016).

Beyond the mental health impacts of extreme events, the gradual impacts of climate change such as temperature increase, poor air quality and drought can exacerbate chronic health conditions and lead to chronic stress. A 10-year study of nearly 2 million US households found that exposure to both more extreme weather and gradual multi-year warming were associated with worsened mental health (Obradovich et al. 2018).

Conclusion

As Missoula County plans for climate resiliency, we are fortunate to have access to a wealth of scientific information about locally-specific climate trends and projections in which to ground our plans. This primer has brought together information from dozens of sources regarding the likely temperature and precipitation changes we will face, and the implications of those changes

for our natural systems, economy, agriculture, cultural systems, and human health. While there is certainty that the climate is changing, much uncertainty remains with regard to specific impacts, and the information contained in this primer will need to be updated in the coming years as conditions change and more information becomes available. Predicting the future will always be an imperfect science, but we have no choice but to prepare the best we can with the information we have. There is much at stake.

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