CLIMATE PROFILE FOR
THE VERDE VALLEY

Climate Profile for the Verde Valley, Arizona

Climate Assessment for the Southwest (CLIMAS)
University of Arizona

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Executive Summary

The earth's climate is changing. Global average temperatures have risen 1.8° F since 1901. Warming temperatures are driving other environmental changes such as melting glaciers, rising sea levels, changes in precipitation patterns, and increased drought and wildfires.

The magnitude of future changes will depend on the amount of greenhouse gases (GHGs) emitted into our atmosphere. Without significant reductions in GHGs, global average temperatures could rise as much as 9° F over pre-industrial temperatures by the end of this century.

The Verde Valley is also experiencing climatic changes that will impact temperatures, precipitation patterns, ecosystems, and human health and well-being. Changes for the region include:

Temperature

Average temperature

- The long-term average temperature for the Verde Valley is 55.8° F. However, almost every year since 1985 has had average annual temperatures above the long-term average.
- These trends are projected to continue into the future. Average temperatures could be 3° F above the current average by 2030 and more than 11° F higher by the year 2100.

Extreme temperatures

- From 1961-1990, the Verde Valley has averaged 25 days per year where the high temperatures reached above 95° F. The region could experience as many as 50 days above 95° F per year by 2030 and as many as 110 days per year by the end of this century. Likewise, the region could experience as many as 75 days per year above 100° F by the end of the century. The current average is eight days per year.
- Minimum temperatures are also expected to rise, which means fewer days when temperatures fall below freezing. By the end of the century, the Verde Valley could experience as few as 45 days per year that reach freezing temperatures. The current average is 115 days per year.

Precipitation

Average precipitation

- Precipitation in this region is naturally variable from year-to-year. There is no clear trend toward changes in *average* precipitation amounts in the Verde Valley. We expect this natural variability to continue in the future.
- However, even with no change in average precipitation, rising temperatures will increase evaporation and transpiration rates, which will lead to drier soils and contribute to more frequent and severe drought.

Extreme precipitation

- Over the past 30 years, the Southwest U.S. has experienced greater totals during heavy rain events associated with monsoon thunderstorms. However, the frequency of such events has fallen, as has the average amount of monsoon precipitation.
- These trends of less frequent storms, decreased average precipitation, but more extreme storms are likely to continue in the future.
- In severe storms, maximum wind gusts have become higher. Higher winds during severe storms are also projected to continue in the future.

Impacts

Human Health

- Extreme heat can affect human health, especially in vulnerable populations (e.g., older adults, children, and those with chronic illnesses) and can strain energy grids as residents increase their use of air conditioning to stay cool.
- Higher temperatures, smoke from wildfires, and dust storms all lead to poor air quality and can create serious health problems, especially in vulnerable populations.
- Climate change may affect certain vector-borne diseases, such as West Nile Virus, because warmer temperatures will create a more welcoming environment for the mosquitos that carry West Nile Virus.

Water Availability

- Colorado River streamflow will likely be reduced in the future, due to higher temperatures, potential changes in precipitation, and reduced snowpack. Water levels in Lake Mead have been dropping since 2000, but reductions in water supply will not impact municipal deliveries in Arizona for some time.
- A substantial reduction in runoff from the Salt/Verde river system is also projected for the future, with a 23% reduction by 2050 and a worst-case reduction of up to 50%, by 2050. Many factors complicate water rights across the region, including hydropower production, irrigation diversions, and population demands from various municipalities.

Wildfire

- Wildfire can pose a direct threat to people and structures as well as cause negative health impacts due to poor air quality. Future fire frequency could increase 25% in the Southwest, and the frequency of very large fires (over 12,000 acres) could triple.

Agriculture

- The growing season is generally considered to be the time between the last freeze (<32° F) in the spring and the first freeze (<32° F) in the fall. In the future, there will be fewer days per year that drop to the freezing point and growing season length is likely to increase by up to 70 days per year by the end of the century.
- Excessive heat, reduced water resources, and wildfires may negatively affect the most common crops grown in the Verde Valley. In particular, increased temperatures may increase pest persistence, heat stress on livestock, and detrimental impacts on crops like winegrapes.

Climate Change Adaptation

Climate change adaptation planning is the process of planning to adjust to new or changing environments in ways that reduce negative effects and take advantage of beneficial opportunities. Climate change adaptation strategies can be integrated into existing community plans, such as landscape or infrastructure management plans or can be stand-alone plans. Adaptation planning is a community-driven process in which community members and leaders should identify and discuss community values, goals, and capacities. In this report, we present a number of suggestions for possible adaptation strategies for the Verde Valley.

Introduction to the Climate Profile

Decisions about how to best manage natural resources or help your community adapt to a changing climate often require long-term records–or data–about both daily ***weather***[1] and the area's ***climate***. Weather data, in its most basic form, is made up of measurements of temperature and precipitation taken at least once a day. When collected at the same locations for a long time, weather data gives us information about the climate of a place. For example, by looking at many years of weather data we can see how prone a region is to droughts, floods, heat waves or cold spells. These historical weather records also reveal ***climate trends***, such as whether a place is getting wetter or drier or warmer or cooler over long periods of time.

Projections of future climate conditions, commonly referred to as ***climate projections***, are developed using computer-based climate models. These models provide us with estimates or ***scenarios*** of possible future climate conditions.

Both observed (historical) data and projected data can be useful in helping a community make decisions about how to adapt to climate ***variability*** and change in the best interests of community members and the surrounding environment. This climate profile has been created for the Verde Valley (which includes the City of Sedona) using surrounding watershed boundaries (see Figure 1). We used observed climate and weather data as well as computer model projections of future climate for the climate analysis. The Verde Valley is an area small enough to be relevant to the City of Sedona and large enough for a robust climate analysis.

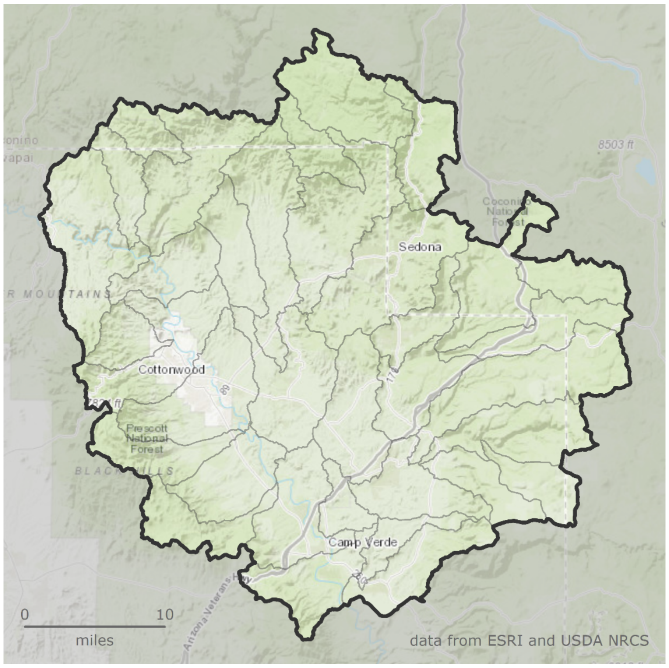

Figure 1: Thirty-five watersheds (gray boundaries) make up the Sedona-Verde Valley study area (black boundary). They are based on Hydrologic Unit Level 6 watersheds in the Watershed Boundary Dataset for Arizona provided by the U.S. Department of Agriculture Natural Resources Conservation Service (https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_064782.pdf). The presented climate summaries correspond to this study area.

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[1] ***Bold/italizized*** terms are defined in the Glossary at the end of the report.

Climate Trends and Climate Change

Global average temperatures are rising. They do not rise everywhere or every year in exactly the same amount. Natural climate variability means that some years are still cold or colder than average. Nevertheless, the world is warming up. Figure 2 shows some of the changes scientists and others have observed about how the Earth is changing. The white arrows indicate upward trends, like rising temperatures and sea levels. The black arrows indicate downward trends, such as the amount of snow in northern and mountain regions.

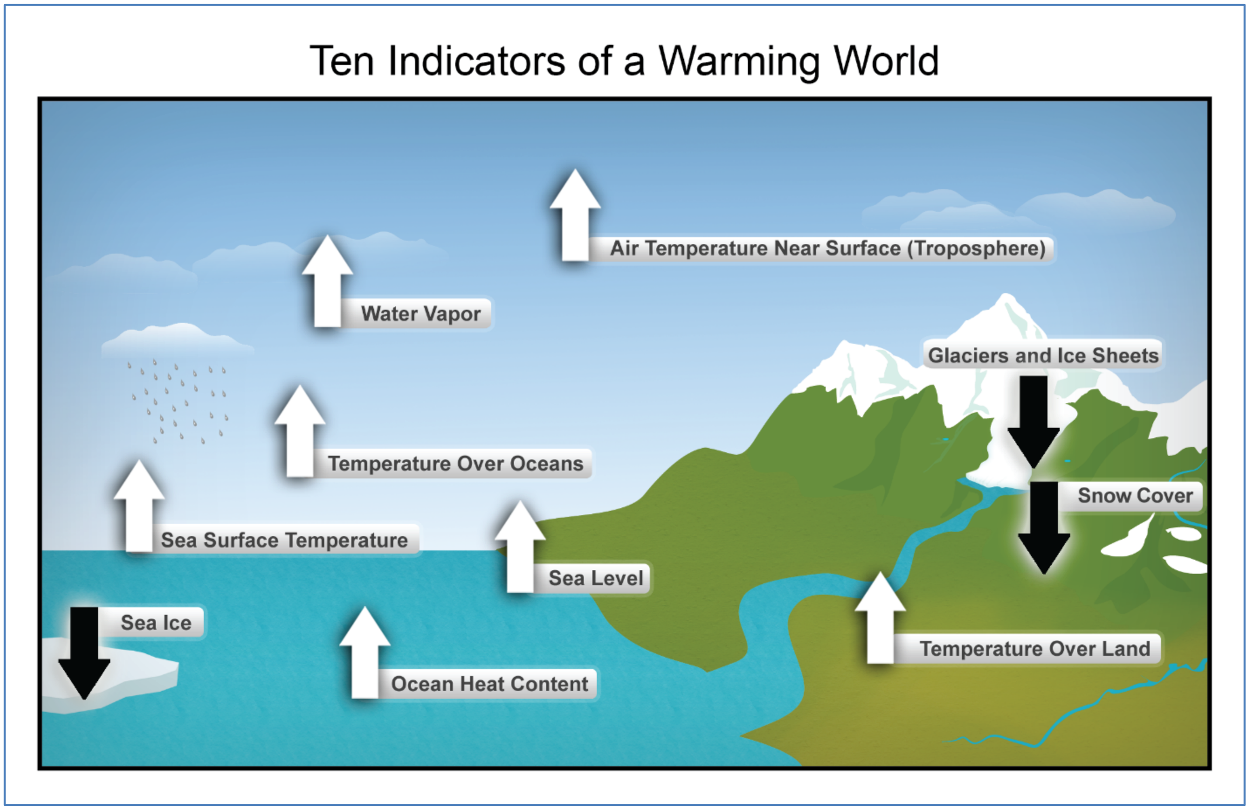

Figure 2: Observed indicators of a warming world. White arrows indicate increasing trends. Black arrows indicate decreasing trends. Source: http://nca2014.globalchange.gov/report/our-changing-climate/observed-change#tab2-images.

While most areas of the United States have warmed in recent decades, not every area has experienced (or will experience) a constant rate of warming (Figure 3). **The Southwest is one of the regions that has experienced the fastest rate of warming – more than 1.5° F in recent decades**. The warming is particularly evident during the winter season.

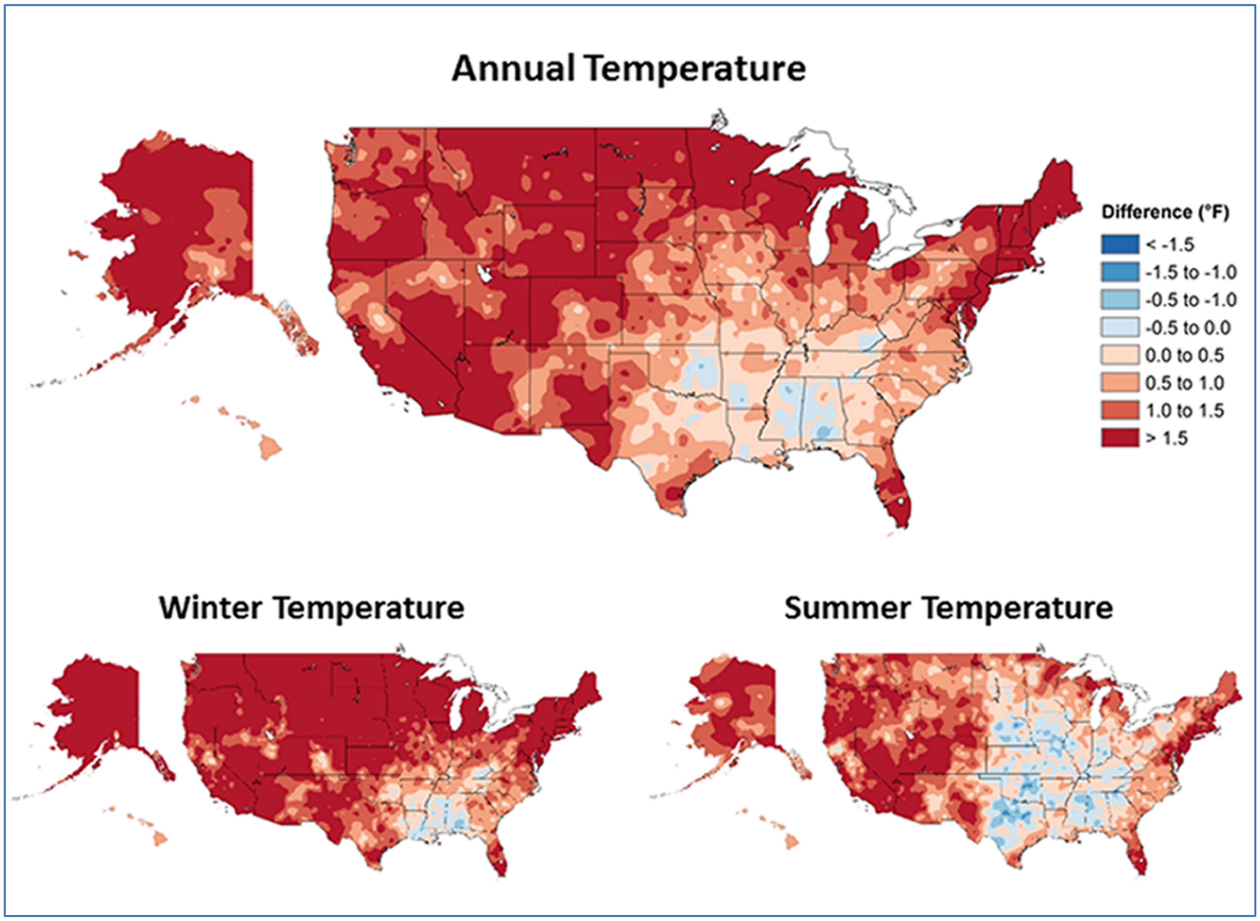

Figure 3: Observed temperature changes in the U.S. comparing the current period (1986 – 2016) to the period 1901–1960. The darker the color, the greater the difference between 1901–1960 and 1986 - 2016. Source: Climate Science Special Report: https://science2017.globalchange.gov/.

Why is the climate changing?

The sun's energy enters the Earth as short wave radiation. The Earth and its atmosphere reflect some of this energy back to space, while some of it naturally passes through the atmosphere and is absorbed by the Earth's surface (Figure 4). This absorbed energy warms the Earth's surface, and is then re-radiated back out to space as long wave radiation. However, some of the long wave radiation does not make it to space, and is absorbed in the atmosphere by ***greenhouse gases (GHGs)***, warming the surface and keeping the planet warmer than it would be without an atmosphere. This natural process is what makes the earth habitable. However, while GHGs are naturally occurring in the atmosphere, human activity is increasing the amounts of GHGs emitted directly to the atmosphere. Carbon dioxide, methane, and nitrous oxide are major GHGs. Carbon dioxide (CO_2) is released through the burning of fossil fuels such as coal, natural gas, and gasoline, and accounts for about 75% of the warming impact of these emissions. Methane (from such sources as livestock, fossil fuel extraction, and landfills) accounts for about 14% of the warming impact from GHG emissions and has a much more potent effect on global warming per unit of gas released. Agriculture contributes nitrous oxide to the atmosphere from fertilizers and livestock waste; it is the most potent GHG and accounts for about 8% of the warming.

By increasing levels of GHGs, humans are intensifying the natural effect of warming the planet. Heat from the sun can still get in, but more and more of it cannot get back out again.

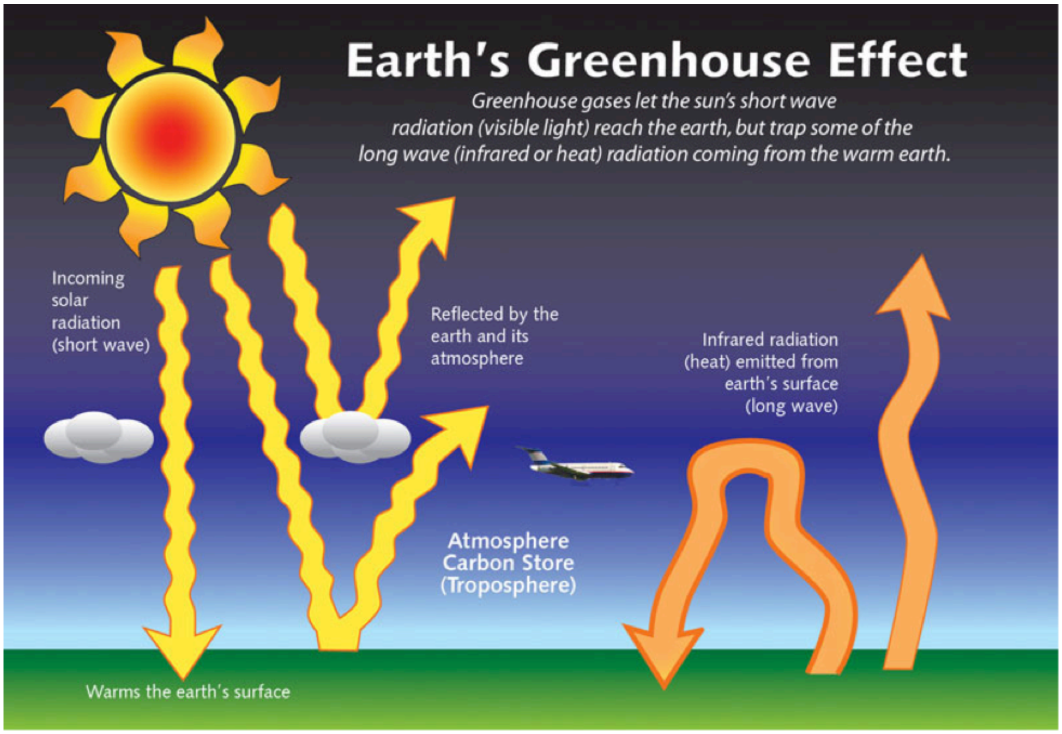

Figure 4: The Greenhouse Effect. Source: New York State *Department of Environmental Conservation;* http://www.dec.ny.gov/energy/76533.html

By comparing the amount of CO_2 in the atmosphere to changes in temperatures, we can see that the rising global temperatures are correlated to rising CO_2 concentrations in the atmosphere (Figure 5). In Figure 5, the blue bars represent years with an average temperature lower than the long-term global average of 57° F and the red bars are years in which the temperature was warmer than average. The black line traces the amount of carbon dioxide in the atmosphere (in parts per million, or ppm).

Although we see a long-term trend toward higher temperatures, there are still year-to-year variations in temperature that are due to natural processes such as the effects of the El Niño Southern Oscillation (ENSO) (a shift in global atmospheric circulation patterns). These variations can cause global temperatures to rise quickly during El Niño years and cool during La Niña years.

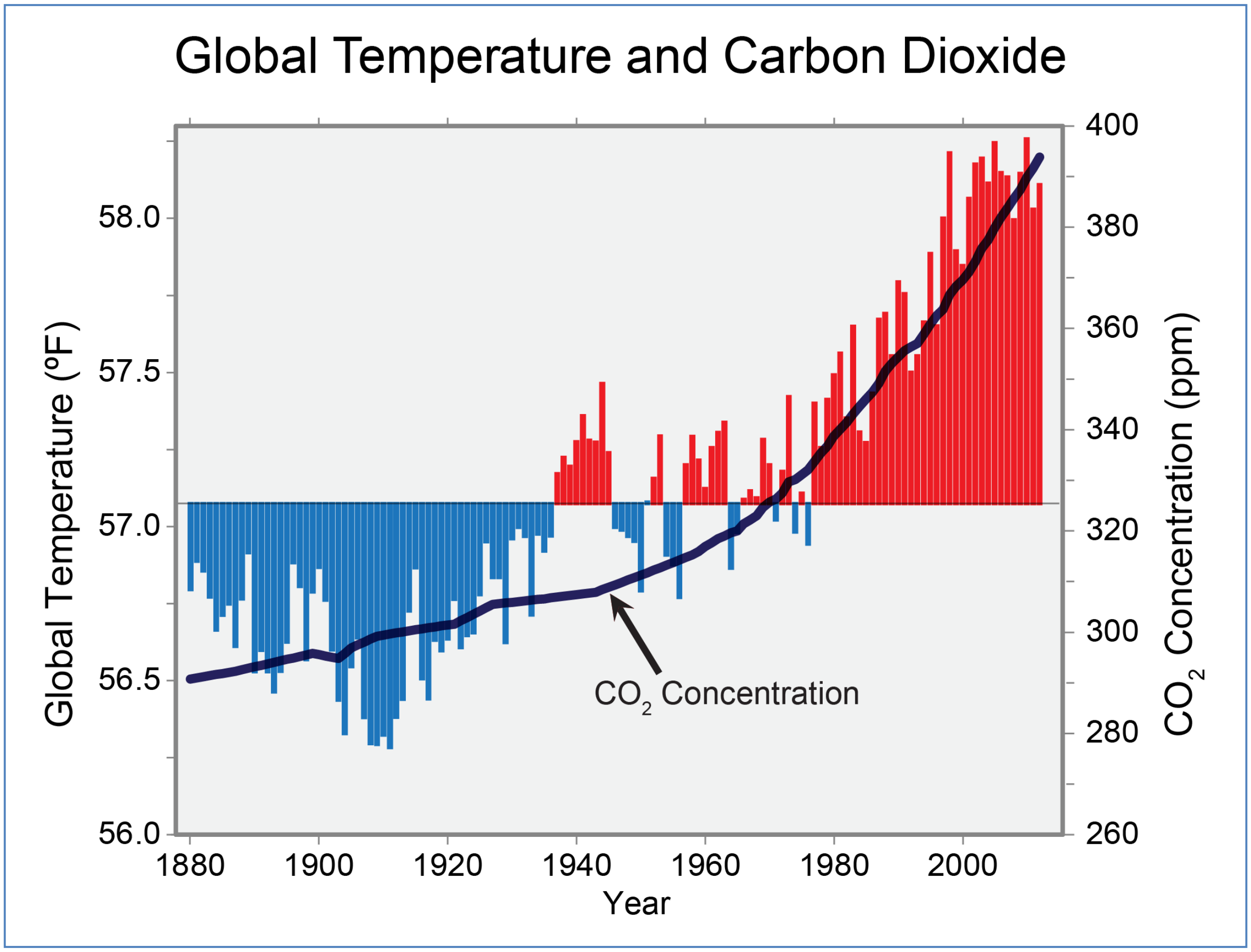

Figure 5: The corresponding rise in CO$_2$ and global temperatures. Source: http://nca2014.globalchange.gov/report/our-changing-climate/observed-change#tab2-images

The strong relationship between temperature and amount of CO$_2$ is apparent, and scientists have been able to perform more detailed experiments to confirm that the increasing amounts of GHGs are the cause of warming. Since a controlled experiment cannot be conducted in the real world by raising and lowering overall GHGs, scientists build mathematical models of the Earth's systems using computers. The graph in Figure 6 shows results of an experiment with climate models in which scientists compared natural warming factors, such as periodic changes in how much energy the Earth receives from the sun and volcanic eruptions, with the temperatures that had been observed since 1895. They found that the natural warming factors (the green shaded area) do not match the observed temperatures. But when they added in human causes – GHG emissions – along with natural processes (the blue shaded area), they found that their results matched very well with the observed temperatures.

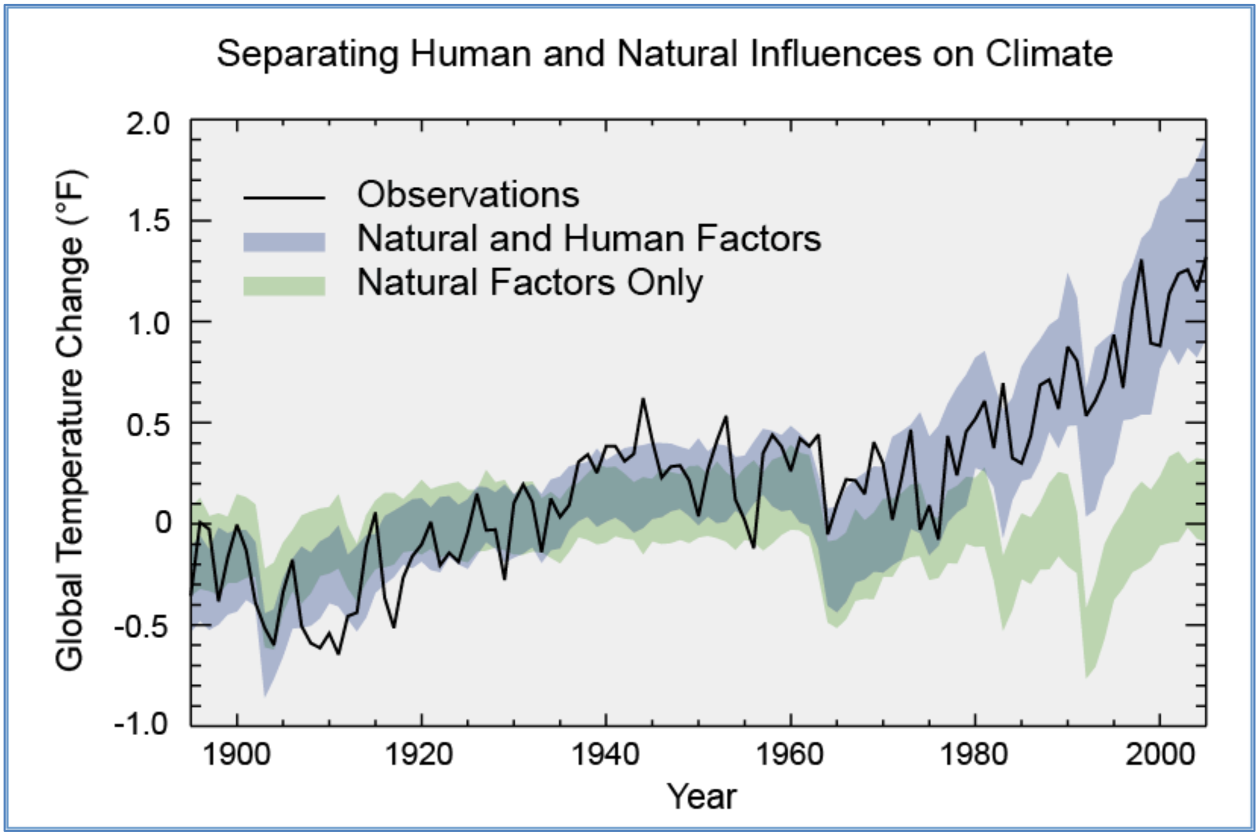

Figure 6: Results from a model experiment to compare natural warming factors with observed temperature changes since 1895. Source: Third National Climate Assessment, http://nca2014.globalchange.gov/report/our-changing-climate/observed-change#tab2-images

Baseline Climate Data for the Verde Valley

To better understand the past and current climate of the Verde Valley, we examined the instrumental weather and climate records from 1895 through the present. We used the Parameter-elevation Regression on Independent Slopes Model (PRISM)[2] dataset, which begins in 1895 with the first consistently recorded instrumental climate records. Climatologists refer to the period from 1895 to the present as the "instrumental record" period. PRISM uses regional weather station observations to estimate climate variables for 2.5-mile (4-km) areas in a continuous grid across the United States (Daly et al. 2002).

The stations used in PRISM mainly come from the National Weather Service Cooperative Observer Program of the National Oceanic and Atmospheric Administration, which have the longest continuous record of weather data. Data from other weather stations are included if they have at least 20 years of data.

PRISM accounts for variations in weather and climate due to complex terrain, rain shadows, elevation, and ***aspect*** – all of which affect weather and climate across the Verde Valley.

Temperature in Historical Perspective

Between 1895 and 2019, the annual average temperature across the Verde Valley was 55.8° F. However, year-to-year the averages have ranged from below 53.8° F in 1912 to 59.8° F in 2017. Although year-to-year changes in temperature are natural and expected in this region, we see a fairly consistent upward trend in annual average temperatures since the mid-1980s. In Figure 7, the straight horizontal line represents the long-term average, and the orange line shows year-to-year average temperatures. **Almost every year since 1985 has seen average annual temperatures above the long-term average**.

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[2] Full URLs for all online resources are included in the Reference section.

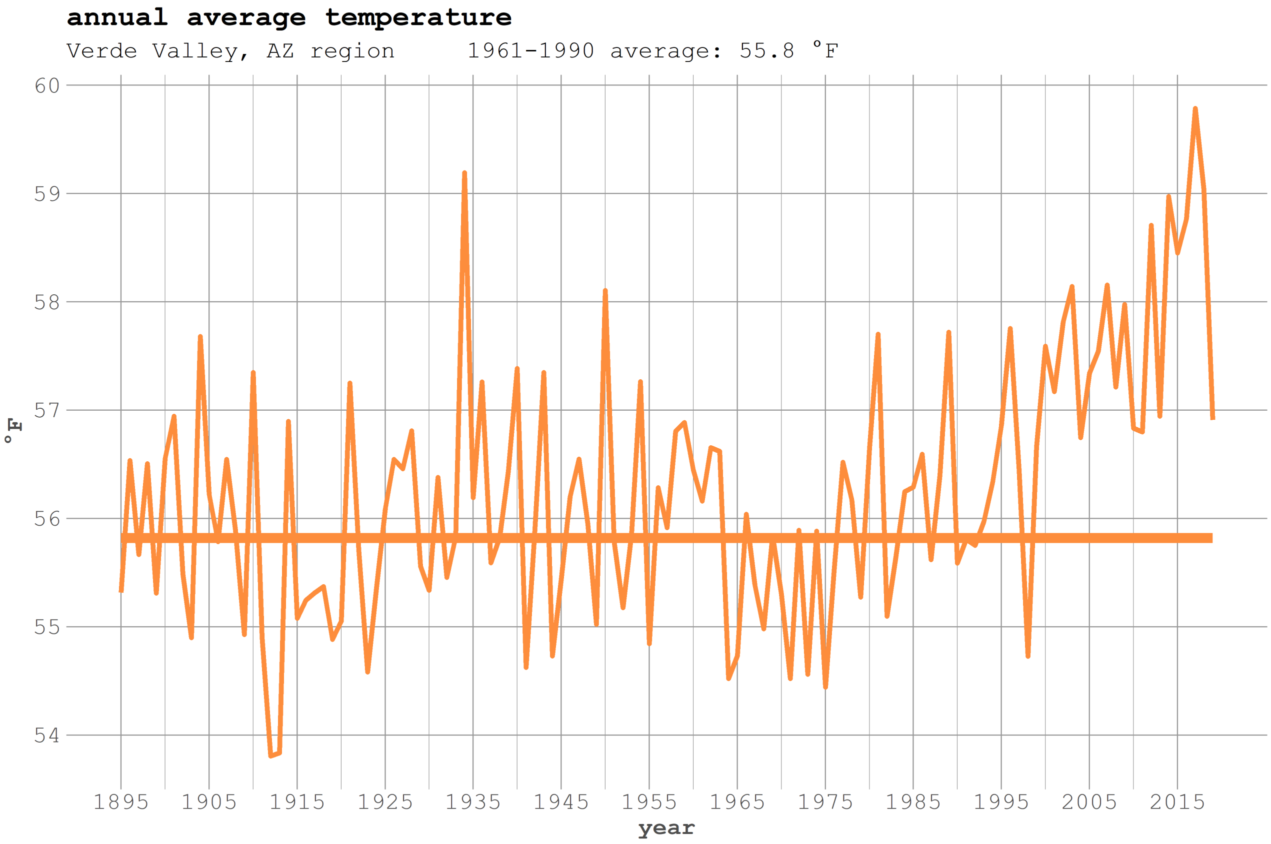

Figure 7: Average annual temperatures for the Verde Valley from 1895 – 2019.

Disaggregating temperatures as average daily maximum, average daily minimum, as well as overall average allows us to identify patterns in how warming is impacting a region. *Maximum* annual average temperature tells us the average of all the warmest, typically afternoon, daily temperature readings in an area. *Minimum* annual average temperature tells us the average of the lowest temperature readings, which typically occur in the early morning. The overall average is the average of both maximum and minimum temperatures for an area over a given time.

In Figure 8, we see that *minimum* annual average temperatures (shown in yellow) for the Verde Valley have been rising faster than *maximums* (shown in red) – although both are rising. This pattern indicates that **the warming trend is mostly being driven by rising low temperatures**, such as days not being as cold and fewer cold days each year (see Temperature Extremes section below on page 24).

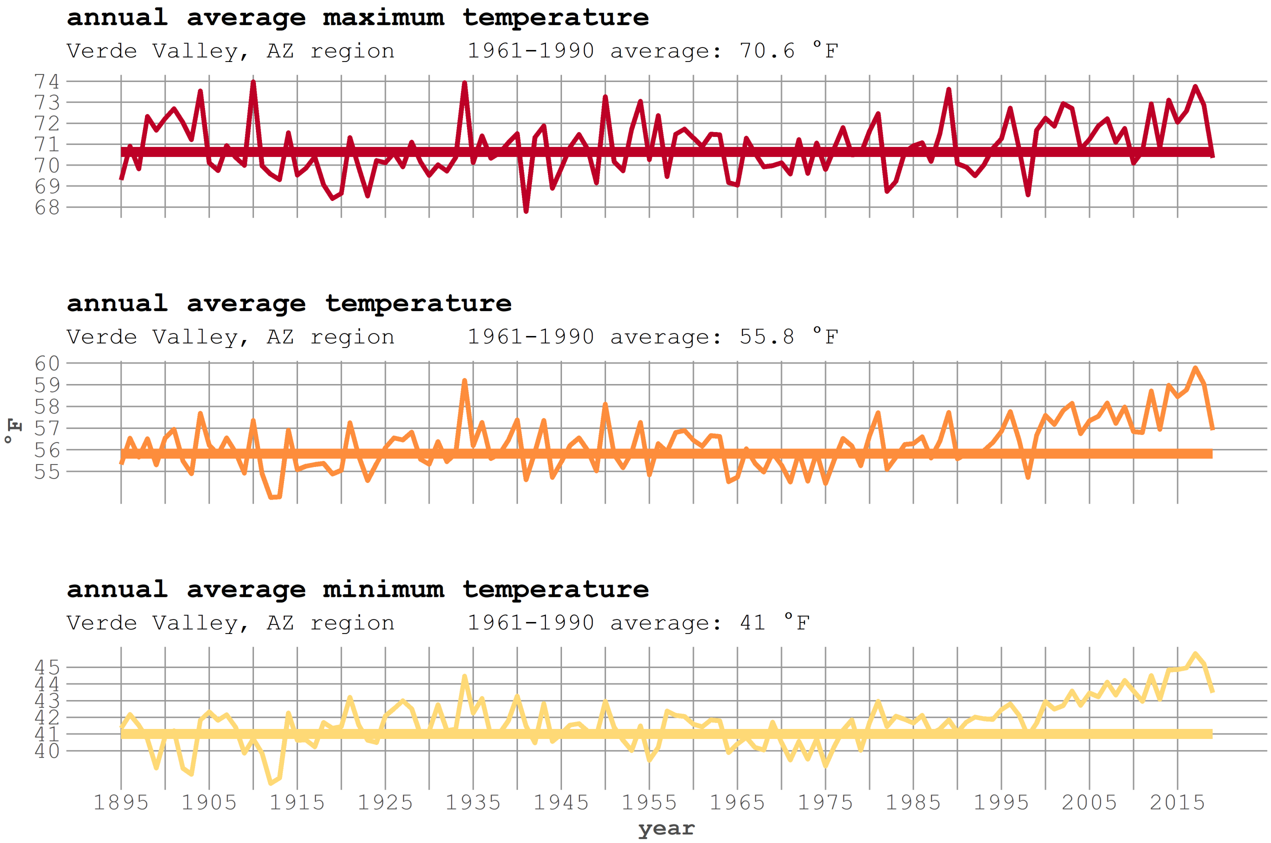

Figure 8: Annual average maximum (red), minimum (yellow), and overall average (orange) temperatures for the Verde Valley from 1895 – 2019.

Precipitation in Historical Perspective

As is normal in the southwestern U.S., precipitation across the Verde Valley is highly variable and has ranged from over 42.4 inches in 1905 to below 8.1 inches in 1956. The average annual precipitation across the Verde Valley between 1895 and 2019 was 20.1 inches (Figure 9). In Figure 9, green bars represent years with above-average precipitation and brown bars represent years with below-average precipitation.

The Verde Valley has experienced two periods of generally above-average precipitation (***pluvials***), which are noted with light green shading. The most distinct pluvials occurred from 1905 through the mid-1920s, and again in the late 1970s through the mid-1990s. Multi-year drought periods (multiple years with below-average precipitation), noted with light brown shading, occurred in the late 1800s to early 1900s, 1940s-early 1960s, and 2000s. These drought periods were felt across a broad swath of the Southwest.

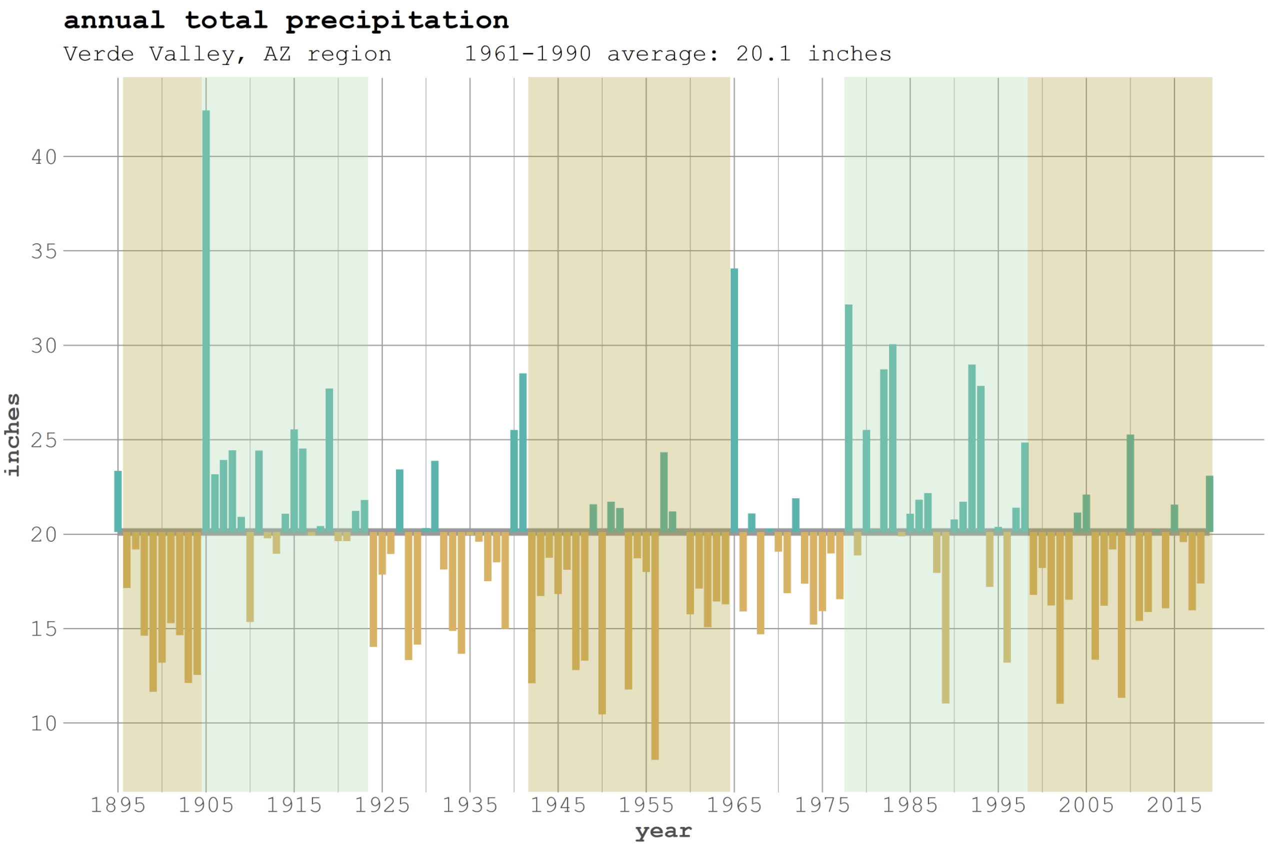

Figure 9: Average annual precipitation for the Verde Valley 1895 – 2019.

Background: Projecting Future Climate Conditions

The Intergovernmental Panel on Climate Change (IPCC), which is the international body of the United Nations responsible for assessing climate changes and impacts across the globe, has used scenarios to project possible future climates for the world as a whole. Different levels of greenhouse gases (GHGs) released into the atmosphere will have different impacts on warming temperatures. In order to show this range of possible outcomes, climate scientists use ***Representative Concentration Pathways (RCPs)***, which are scenarios based on assumptions about global levels of economic activity, energy sources, population growth, and other socio-economic factors that influence the rate of GHG emissions. These scenarios are then used in Global Climate Models (GCMs) to estimate future global average temperatures and other climate variables.

Table 1 summarizes the assumptions and projections for the RCPs and Figure 10. Figure 10 illustrates the temperature changes expected with each scenario. At both global and regional scales, the scenarios result in projected changes that are similar until the year 2050, but diverge at that point. This is due to the differences in when each scenario assumes GHG emissions will begin to be reduced.

Table 1. Assumptions and Projections for each Representative Concentration Pathway, represented in Figure 10.

Scenario	**Assumptions**	**Projected Temperature Increase**
RCP 2.6 *green line and shading*	"Best Case Scenario" - assumes that through policy intervention, GHG emissions begin decreasing by 2020 and decline to around zero by 2080, leading to a slight reduction in today's GHG levels by 2100.	Global average temperatures increase 2.5° F (1° C) by 2100 (relative to the 1986 – 2015 average).
RCP 4.5 *aqua line*	Assumes that GHG emissions will peak at around 50% higher than year 2000 levels in about 2040 and then fall.	Global average temperatures increase 4° F (1.8° C) by 2100 (relative to the 1986 – 2015 average).
RCP 8.5 *red line and shading*	"Business as Usual" - Assumes GHG emissions continue to grow at current rate through 2100.	Global average temperatures increase more than 8° F (3.7° C) by 2100 (relative to the 1986 – 2015 average).

Figure 10 shows the projected global temperature increases under the emissions scenarios (described in Table 1). The green line represents the low emissions scenario (RCP 2.6). The blue line represents the moderate emissions scenario (RCP 4.5). The red line represents the high emissions, or business-as-usual, scenario (RCP 8.5). The black line represents the observed emissions (left panel) and the observed global temperature (right panel). Our global GHG emissions are closest to the red, RCP 8.5 line. We can assume that future temperatures are likely to be closer to the business-as-usual scenario temperature projections if this emissions trend continues. Although there is a range of possible temperatures for each scenario, they all project rising temperatures.

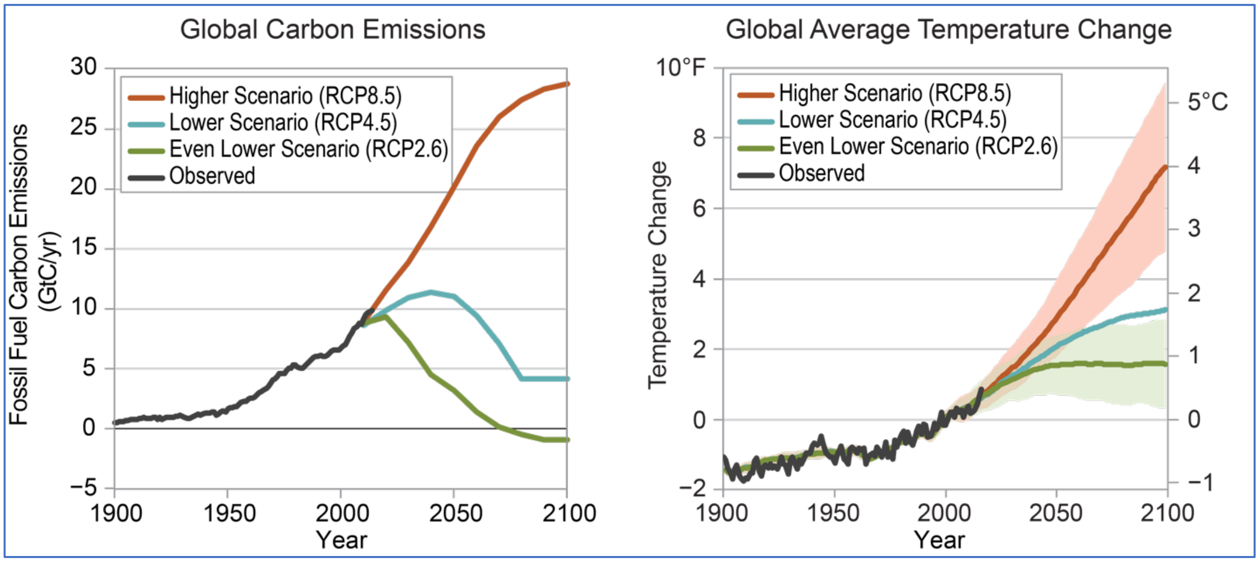

Figure 10: Observed and projected changes in global average temperature (right) depend on observed and projected emissions of carbon dioxide from fossil fuel combustion (left) and emissions of carbon dioxide and other heat-trapping gases from other human activities, including land use and land-use change. Source: Fourth National Climate Assessment; https://nca2018.globalchange.gov/chapter/2#fig-2-2Strengths and Limitations of Climate Models

Global and regional climate models represent, as accurately as possible, the complex atmospheric, oceanic, and other processes that affect the climate. Although they are not perfect representations of the Earth's systems, they have proven remarkably accurate in simulating the climate change we have experienced to date, particularly in the past 60 years, when we have greater confidence in observations. The observed signals of a changing climate continue to become stronger and clearer over time, giving climate scientists increased confidence in their findings (Jay et al. 2018).

Despite their increasing accuracy, climate models still have some limitations that should be kept in mind when seeking to understand projections for the globe or any given region.

- Climate model projections are not designed to predict year-to-year variations in climate conditions; they capture long-term changes, such as changes over decades.
- Projections are based on a set of scenarios of possible GHG emissions and how those are likely to affect the climate system. These are possible future conditions – *not predictions* of future conditions.
- Climate scientists are confident in the direction of change the models show – things are getting warmer under all scenarios and in the observed record. However, there is less certainty about the ***magnitude of change***, or exactly how much warming will occur.

Climate scientists increase their level of confidence by using multiple models in their analyses (not relying on just one source of data). The projection data presented in this report come from a combination of 32 climate models. As the 2018 Fourth National Climate Assessment notes, the biggest source of uncertainty in future climate projections is not within the climate models themselves, but in our choices as humans in how we respond to the climate crisis and how that affects the actual GHG emissions (Jay et al. 2018). Climate scientists have high confidence in our understanding of the greenhouse effect and the knowledge that human activities are changing the climate in unprecedented ways. **There is enough information to make decisions based on that understanding**.

Climate Data, Uncertainty, and Decision Making

Many of the decisions we make every day are based on less-than-perfect knowledge. For example, while GPS-based applications on smartphones can provide a travel-time estimate for our daily drive to work, an unexpected factor like a sudden downpour or fender bender might mean a ride originally estimated to be 20 minutes could actually take longer. Fortunately, even with this uncertainty we are confident that our trip is unlikely to take less than 20 minutes or more than half an hour—and we know where we are headed. We have enough information to plan our commute.

– Guidance from the Fourth National Climate Assessment (Jay et al. 2018)

We used the Localized Constructed Analogs (LOCA) dataset for the projections of future climatic conditions presented in this report. LOCA is a technique for ***statistically downscaling*** global and spatially coarser model projections of future climate. The LOCA downscaled climate projections provide temperature and precipitation at grid cells that are 6 kilometers (3.7 miles) across. We included all LOCA cells that intersect with the Verde Valley portrayed in Figure 1. LOCA preserves extreme hot days and heavy rain events better than the previous generation of downscaling approaches and is used in the U.S. Fourth National Climate Assessment (Jay et al. 2018). The data cover the period 1950-2100, use 32 global climate models, and provide analyses based on the RCP 4.5 and 8.5 scenarios discussed above.

In the following discussion, we use the time period 1961 – 1990 as a reference period by which to compare projected changes to current conditions (as opposed to the longer-term instrumental record used above). This reference period aligns with one used for the most recent National Climate Assessment, so changes in the Verde Valley can more easily be compared and contrasted with those occurring in other communities and other regions around the country. The Climate Explorer is a tool that allows for easy comparison.

Projected Temperatures for the Verde Valley

Downscaled model projections for the Verde Valley (Figure 11) show a range of possible future temperature increases, from almost 6° F higher than the 1961-1990 average for RCP 4.5 (orange line and shading) to over 11° F higher for RCP 8.5 (red line and shading) by the year 2100[3]. If GHG emissions continue at their current rate, the region could be significantly warmer, as indicated by the higher (RCP 8.5) scenario. **The projections for the Verde Valley average temperature are even higher than projections for the global average temperature.**

The current annual average temperature for the Verde Valley is 55.8° F. Projections for the year 2050 range from 4° F (lower scenario) to 6° F (higher scenario) above the current average, bringing average temperatures to 59 - 61° F, which is similar to the current average temperature of

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[3] Annual values of differences in average temperature relative to the period 1961-1990 and based on daily 1/16-degree Localized Constructed Analogs statistical downscaling of CMIP5 global climate model projections (loca.ucsd.edu) using RCPs 4.5 and 8.5. Averages are computed from data overlying the Verde Valley area shown in Figure 1.

Albuquerque, NM. By the end of the century, annual average temperature could be between 62° F (lower scenario) and 67° F (higher scenario). For comparison, annual average temperature in Tucson, AZ now is approximately 68° F.

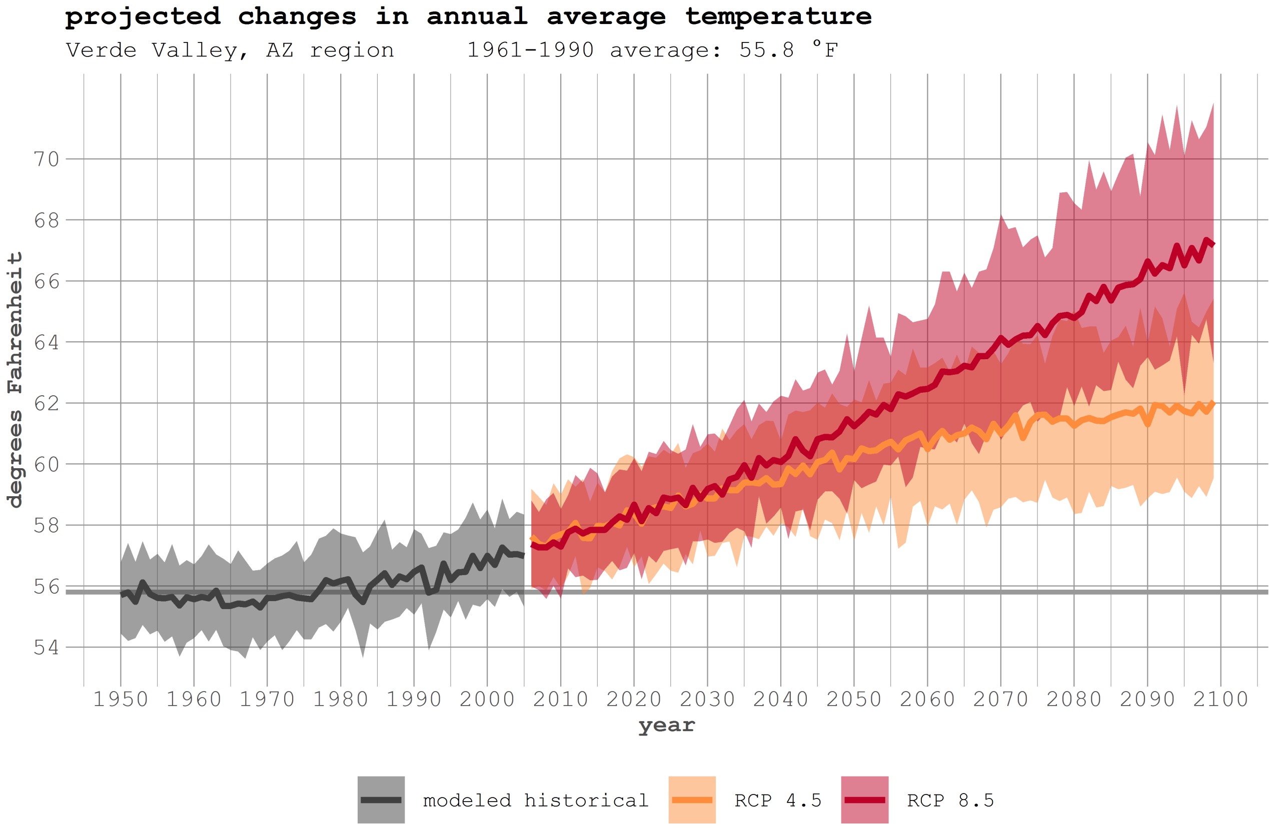

Figure 11: Downscaled model projections for the Verde Valley show a range of possible future temperature increases, from 6° F higher than the 1961–1990 average for RCP 4.5 (orange line) to 11° F higher for RCP 8.5 (red line) at the end of this century.

Precipitation Projections for the Verde Valley

While the projections for *temperature* show possible increases in both scenarios, **the projections show little-to-no change in annual total *precipitation* for the Verde Valley** (Figure 12).[4] The light blue line, representing the lower scenario, shows no change in the amount of annual precipitation by the end of the century. The dark blue line, representing the higher scenario, shows the potential for a slight decrease (1-3 inches) in annual total precipitation by the end of the century. However, given the uncertainty of these projections (discussed in the paragraph below), many climate scientists recommend assuming that annual total precipitation in the region will remain relatively consistent, with year-to-year variation as we see now.

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[4] There is a slight difference between the modeled historical precipitation data and the observed record data. Figure 12 contains a modeled historical average of 19 inches per year, while the observed record is 20.1 inches per year. This is due to the challenge of accurately capturing a particularly complex precipitation regime in climate models. Because the observed record falls well within the model spread (grey shaded area), we retain confidence that the models are representing the climate system as well as currently possible.

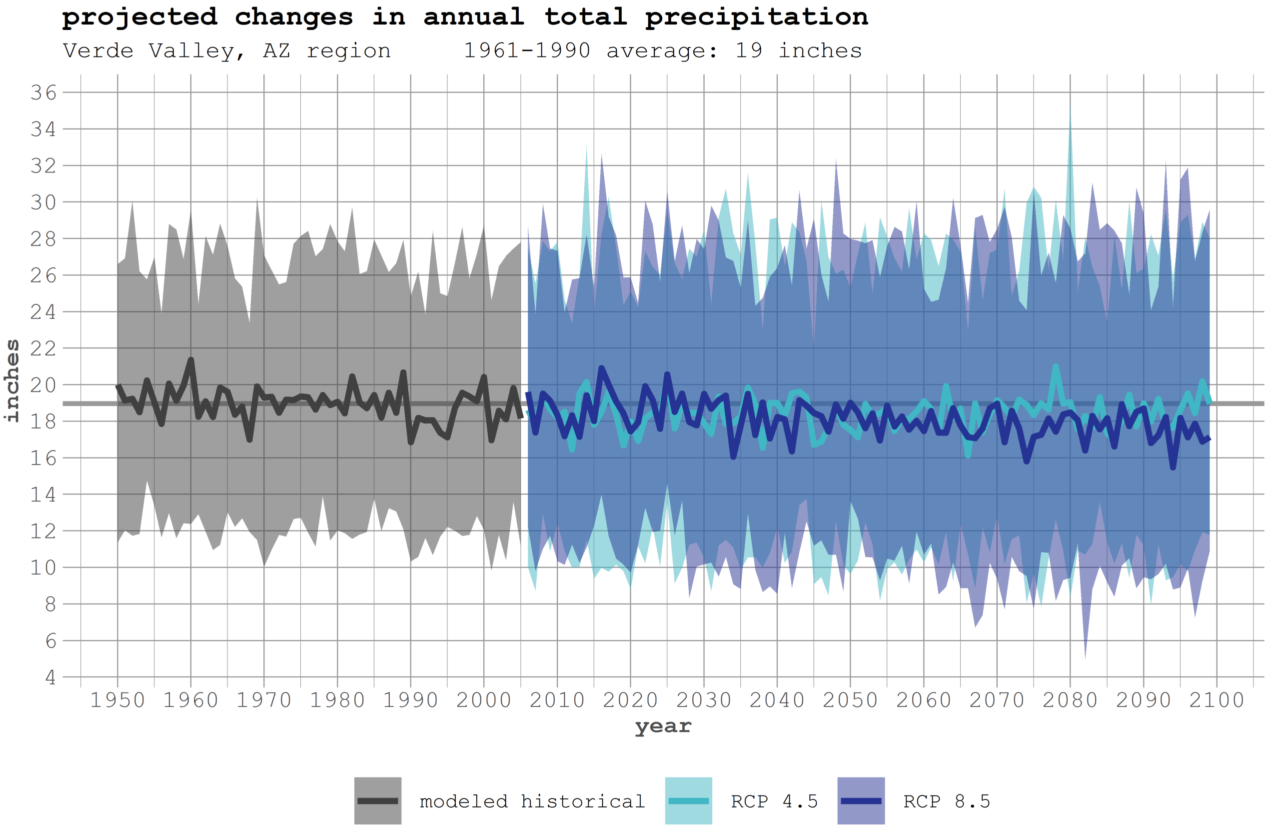

Figure 12: Downscaled projections of annual total precipitation for the Verde Valley, using RCPs 4.5 and 8.5. No trend in future precipitation is clear from the analysis—annual total precipitation appears to remain about the same (19 inches/year) into the future.

Projections for seasonal precipitation give a fuller picture of how precipitation may change at different times of the year. The four figures below (Figures 13–16) show precipitation for each season. Seasons show little to no change in precipitation, just as with annual average precipitation, except for spring (Figure 14), which shows a potential decrease of about 1-1.5 inches by the end of the century. If the Verde Valley does see a decline in precipitation, it is more likely to come in spring than other seasons.

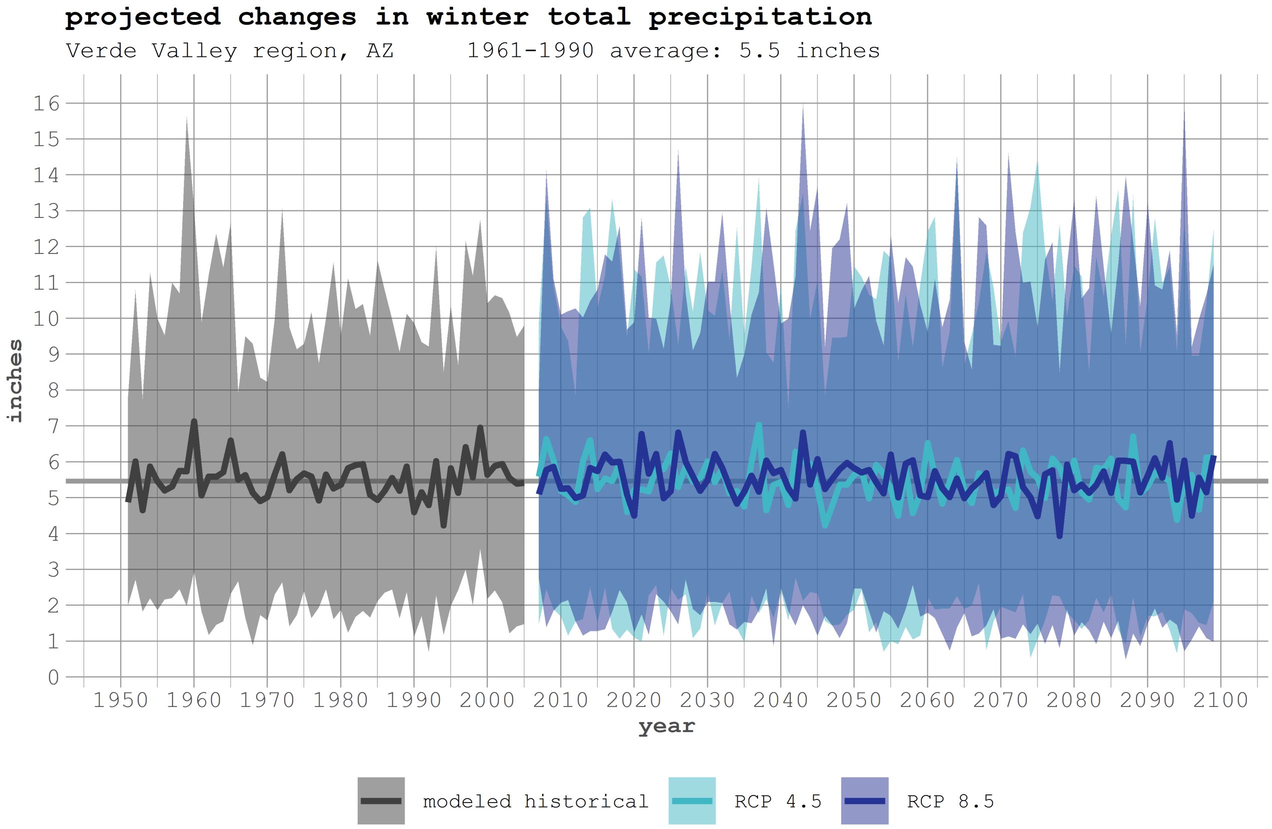

Figure 13: Projected changes in precipitation during December – February for the Verde Valley.

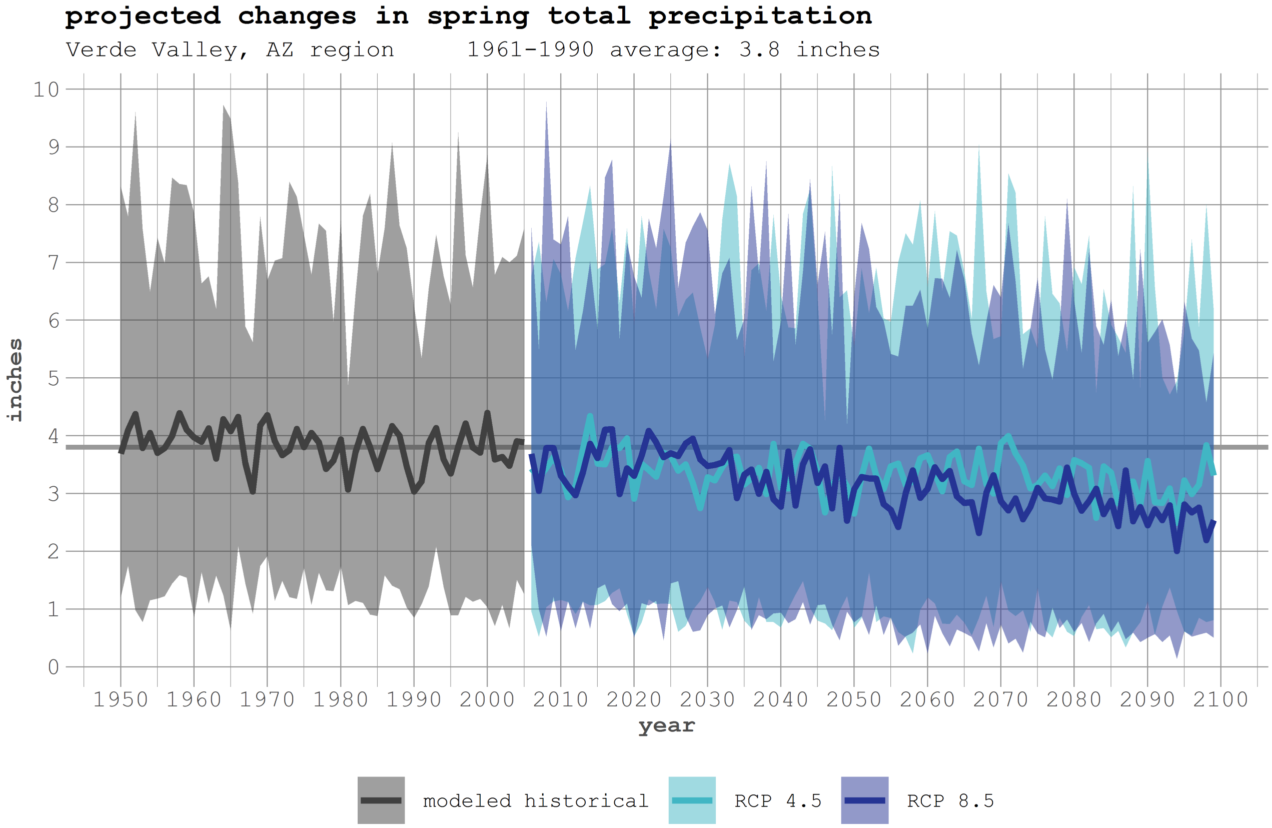

Figure 14: Projected changes in precipitation during March – May for the Verde Valley.

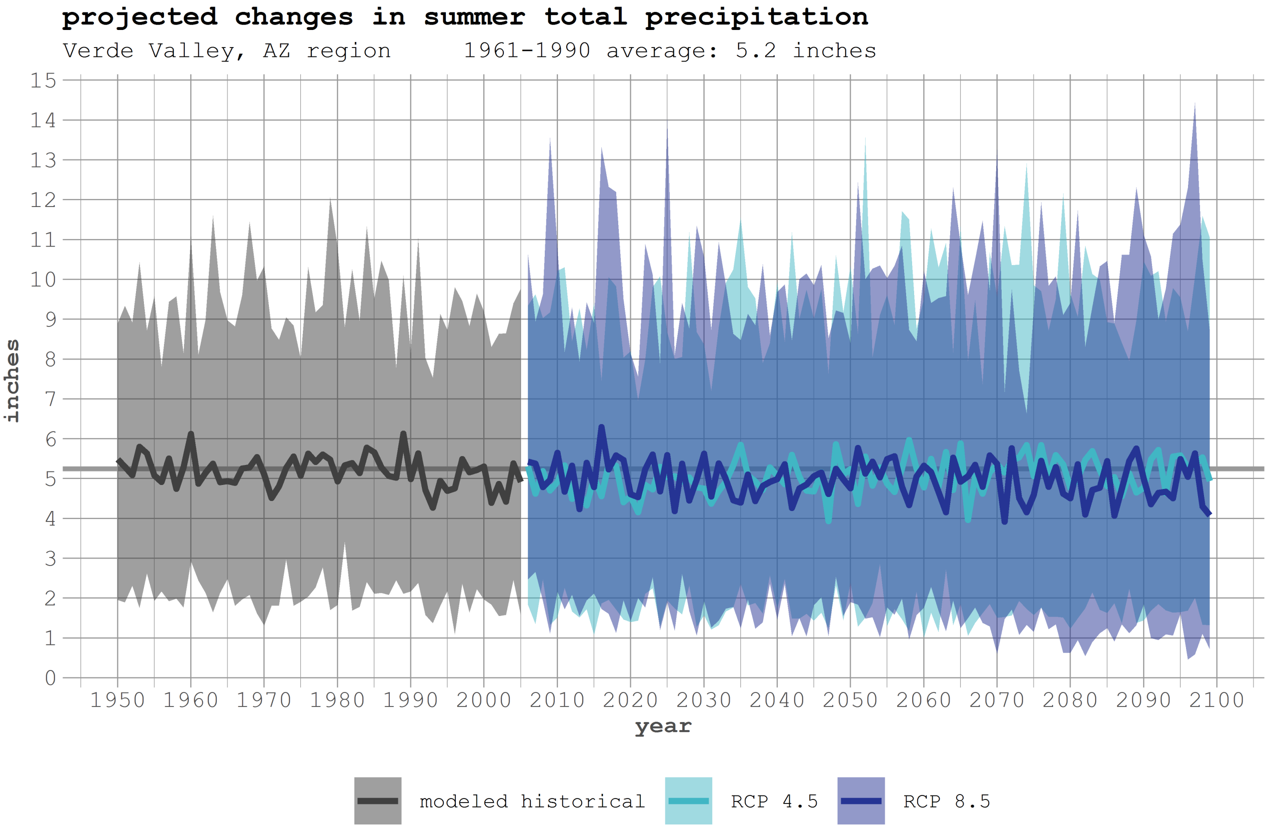

Figure 15: Projected changes in precipitation during June – August for the Verde Valley.

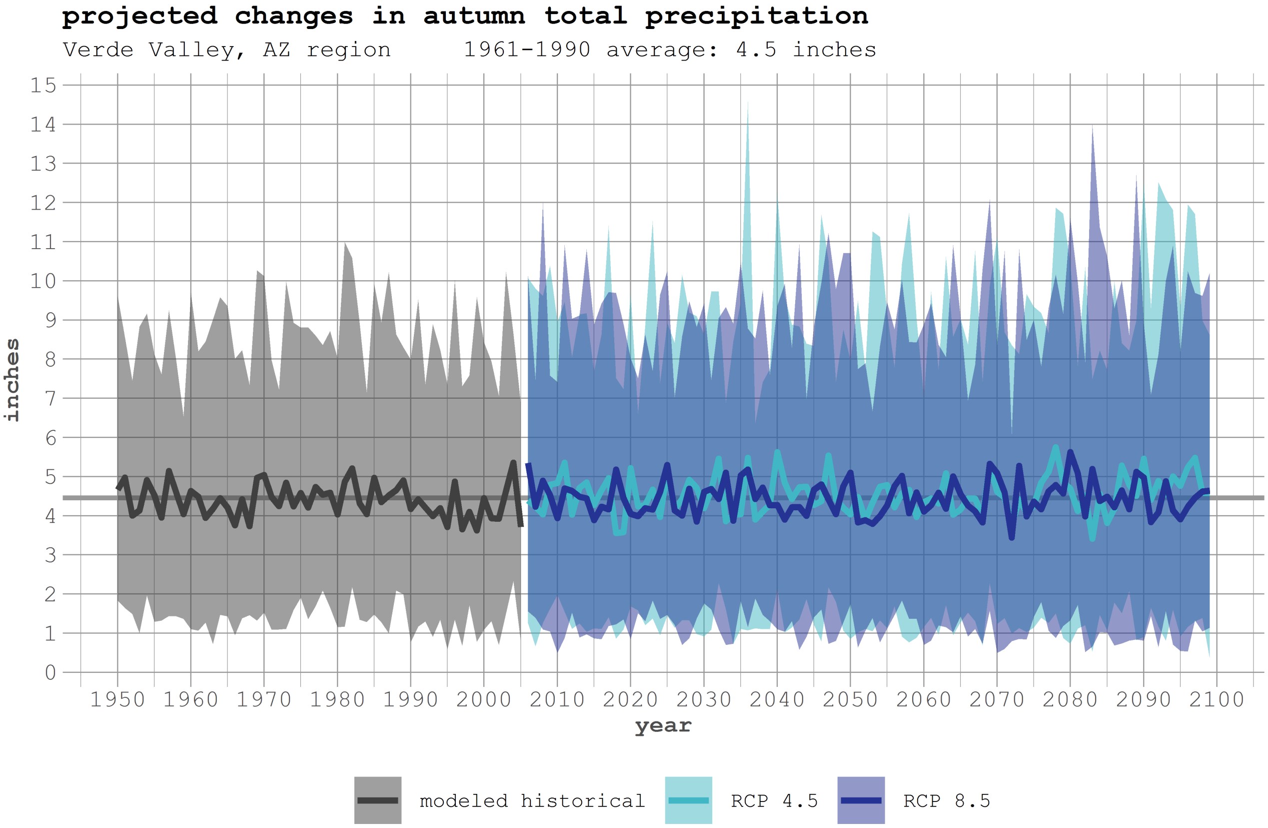

Figure 16: Projected changes in precipitation during September – November for the Verde Valley.

It is important to note that modeling precipitation for this region has proven very difficult, due to the multiple phenomena that influence this region, including the El Niño Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), the North American Monsoon (NAM), and atmospheric rivers (narrow corridors of concentrated moisture in the atmosphere that lead to extreme precipitation events in the western U.S.). Projections of annual average precipitation in the Southwest region are less certain than projections of future precipitation in other parts of the country (Gershunov et al. 2013)[5]. However, **even if there is no change in total precipitation, the Verde Valley could become much drier as projected warmer temperatures will mean more evaporation of surface water and more transpiration (use of water by plants), which will further dry the soil, with the potential changes in soil moisture particularly large in the winter and spring (Figure 17). Additionally, higher temperatures in the winter will result in more precipitation falling as rain than snow, and higher spring temperatures will mean earlier snowmelt, all of which will likely lead to reduced snowpack and streamflow.**

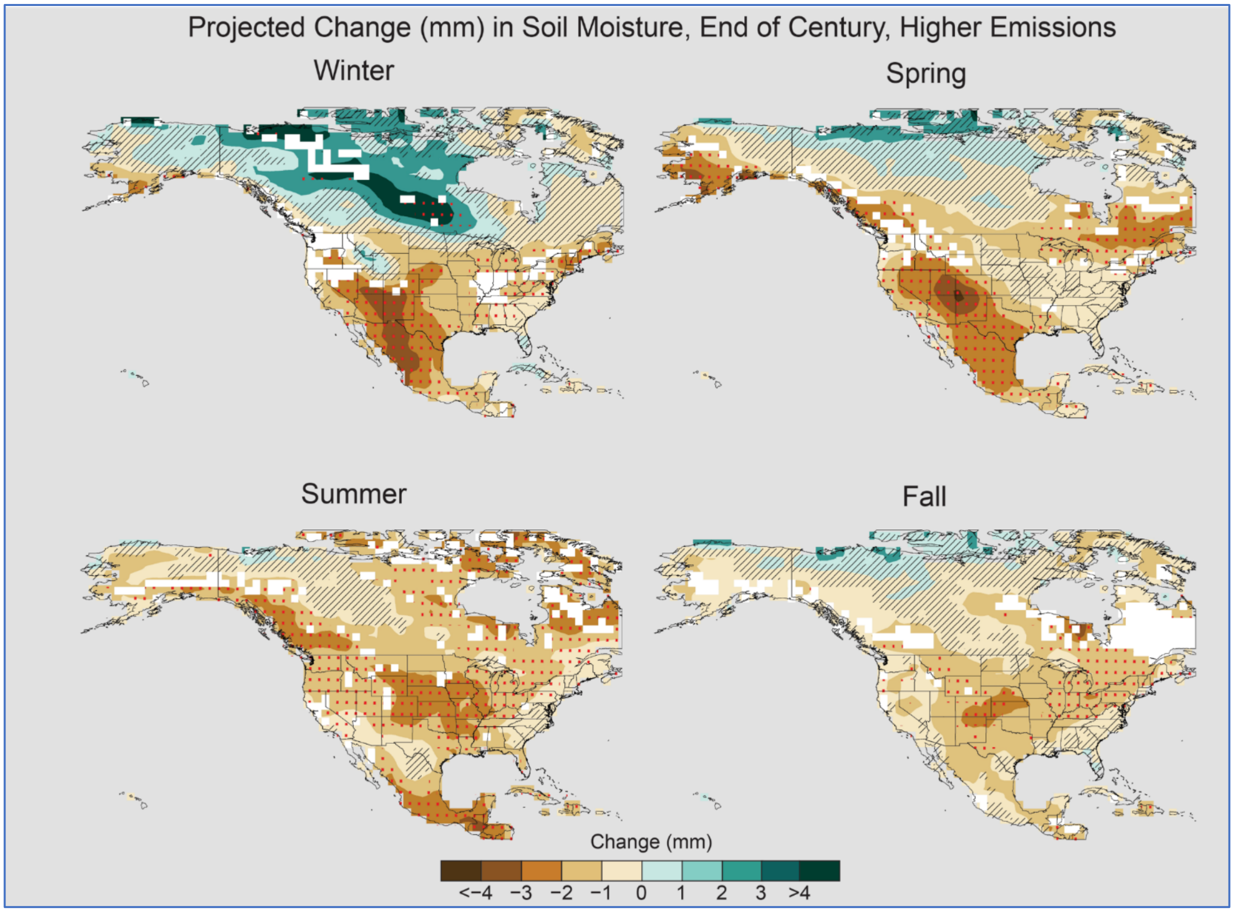

Figure 17: Projected changes in soil moisture by 2100 using the high emissions scenario. Source: https://science2017.globalchange.gov/chapter/8/

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[5] The authors of the 2013 Assessment of Climate Change in the Southwest United States expressed only medium-low confidence in projections related to precipitation changes in the region (Overpeck et al. 2013).

Changes in Character of Precipitation

Recent research on the North American Monsoon (NAM) and atmospheric rivers (ARs) points to changes that may affect the Verde Valley. Warmer temperatures are related to expansion and intensification of the monsoon ridge, with a net result of fewer storms across Arizona during the peak of the monsoon season (late-July to mid-August) (Lahmers et al. 2016). This generally has led to a decline in seasonal precipitation totals during the last 30 years (1980–2010) as compared to the period from 1948–1979, particularly in low-elevation desert areas (Luong et al. 2017). Even though there have been fewer storms, the heaviest rain events have become more extreme (as measured by the amount of precipitation and wind gusts). This is because a warmer atmosphere can hold more moisture, which in turn can contribute to more extreme precipitation events. Between 1980 and 2010, during the latter part of the monsoon (mid-August to September), some higher elevation areas have experienced increases in total precipitation amounts as thunderstorms that develop over this terrain (such as parts of northern Arizona) have moved less frequently into the lower deserts. These storms have stayed in more mountainous areas, which also increases the flood potential in those areas (Lahmers et al. 2016). These patterns are projected to continue into the future**. While the overall average amount of precipitation may not change substantially, the Verde Valley may receive that precipitation in fewer, but more intense storms** (Castro 2017).

Another mechanism for extreme precipitation is ARs. From 1979–2011, ARs accounted for about 25% of the total cool season precipitation for the Verde River Basin, in just a few extreme events (Rivera, Dominguez, and Castro 2014). The frequency and intensity of ARs is projected to increase in the future, increasing the risk for flooding from these storms.

Projected Temperature Extremes

The average number of days above 95° F in the Verde Valley is 25 days per year (between 1961 and 1990). **The projected change in the number of days above 95° F** (Figure 18) **by 2100 range from just under 70 days per year (lower scenario) to as many as 110 days per year (higher scenario).**

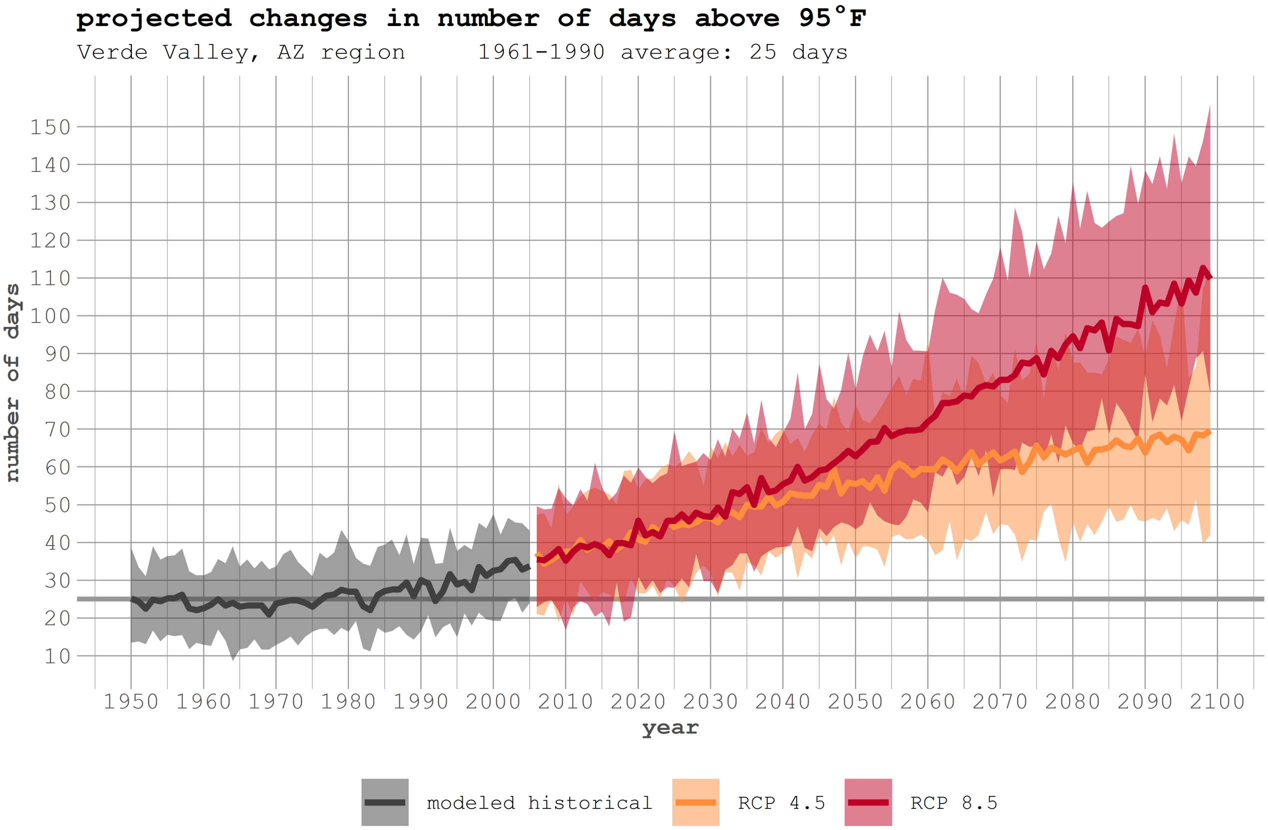


Figure 18: Projected changes in number of days in which maximum temperatures reach at least 95° F in the Verde Valley.

The average number of days above 100° F in the Verde Valley is 8 days per year (between 1961 and 1990). **The projected change in the number of days above 100° F** (Figure 19) **by 2100 range from about 35 days per year (lower scenario) to as many as 75 days per year (higher scenario).**

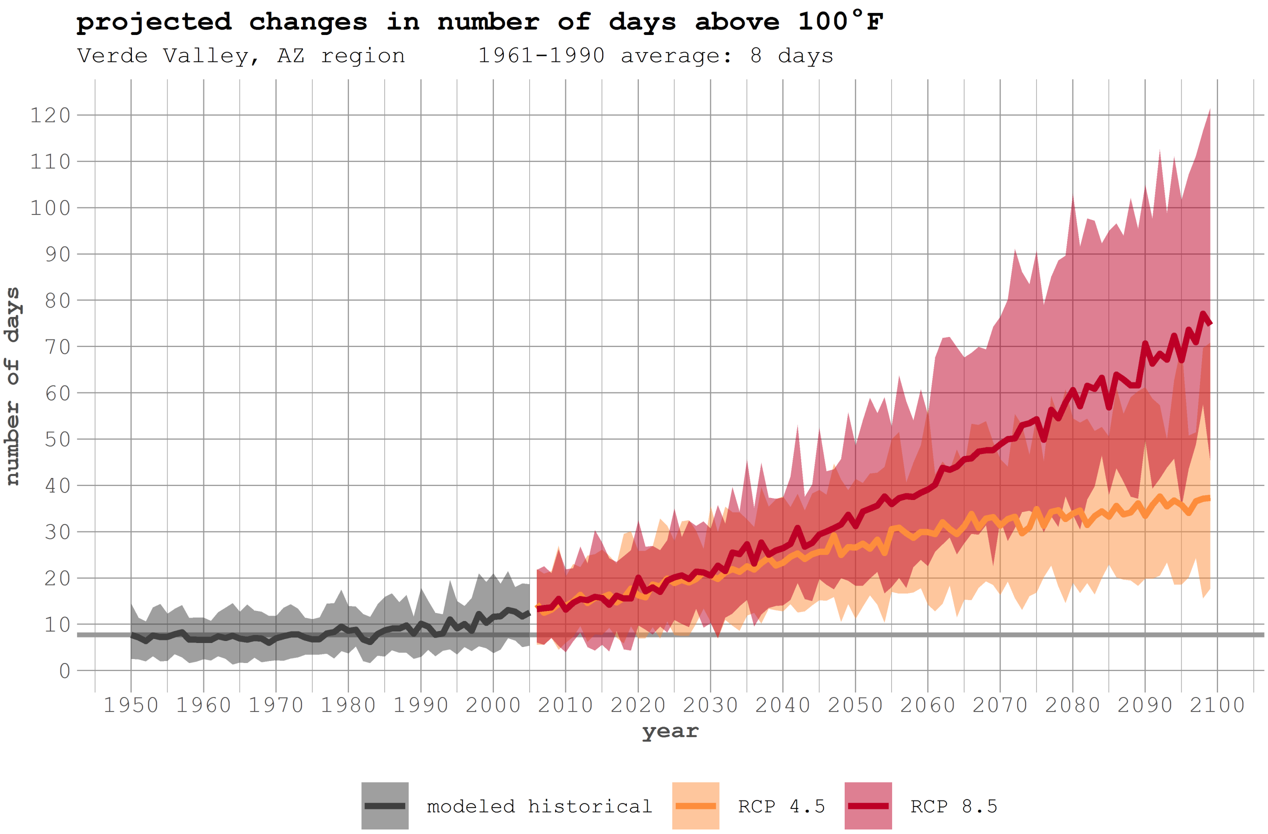


Figure 19: Projected changes in number of days in which maximum temperatures reach at least 100° F in the Verde Valley.

On average, the Verde Valley has experienced 115 days per year in which the minimum temperature is 32° F or colder. Projections for the region indicate that the number of days that fall below the freezing point could decrease by 40 to 70 days, for RCPs 4.5 and 8.5, respectively (Figure 20). **By the year 2100, the Verde Valley could experience as few as 45 days that reach freezing temperatures**.

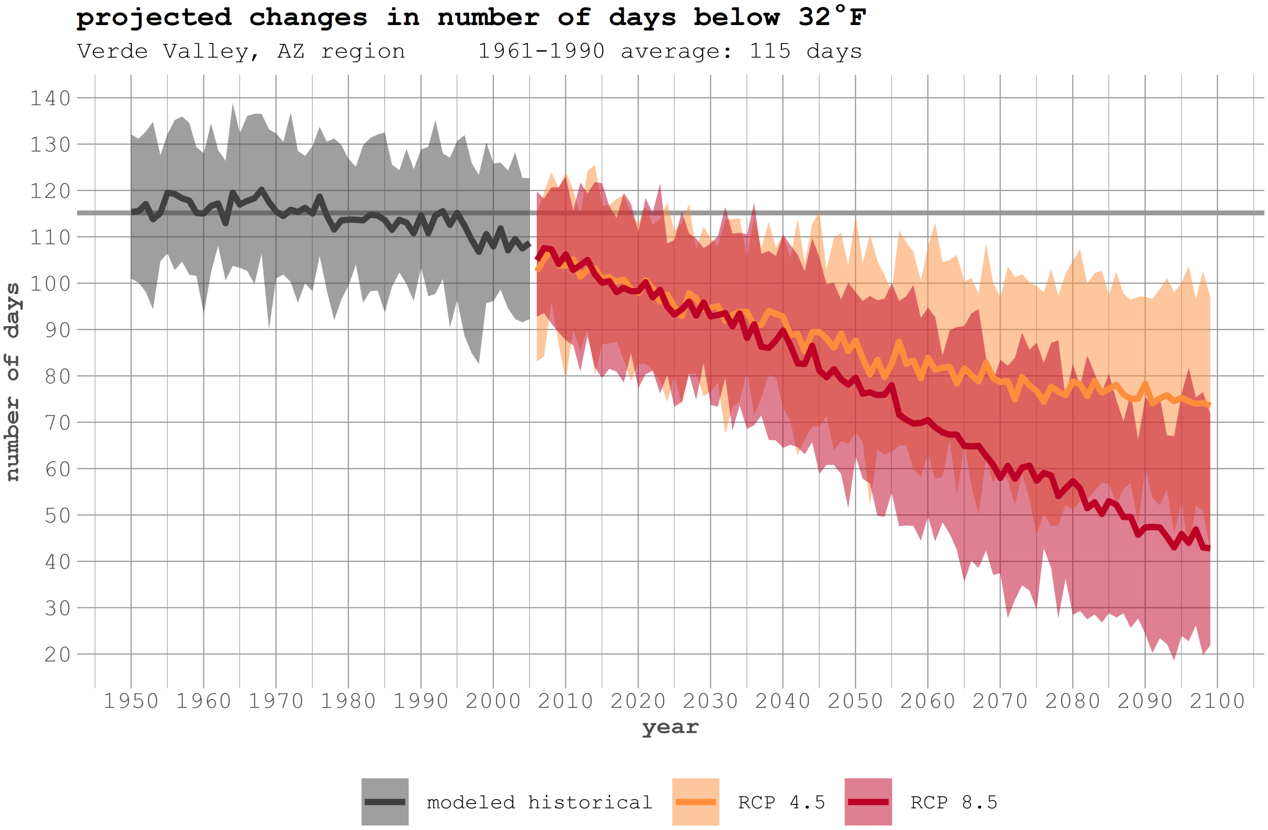


Figure 20: Projected changes in number of days in which minimum temperatures fall below 32° F.

The growing season is generally considered to be the time between the last freeze (<32° F) in the spring and the first freeze (<32° F) in the fall. The growing season in the Verde Valley was about 181 days per year between 1961 and 1990. Based on the projected temperature changes for the Verde Valley, the growing season is likely to increase by between about 40 days (RCP 4.5) and 70 days (RCP 8.5) by the end of the century (Figure 21).

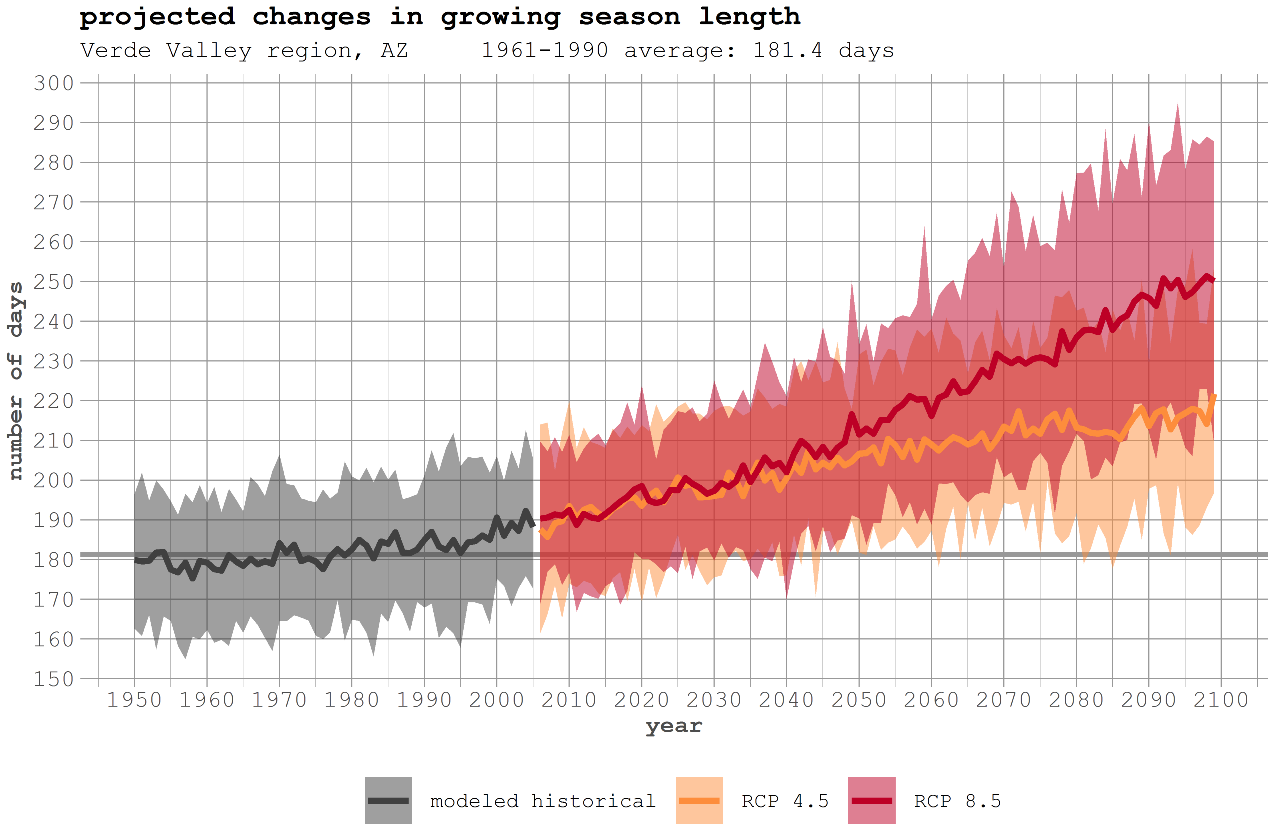


Figure 21: Projected changes in the length of the growing season for the Verde Valley.

Impacts of Climate Change

This overview of impacts from climatic changes is based on a literature review of impacts to the general region of central and northern Arizona. The information provided here can help to place the Verde Valley specific climate projections into a regional context. This section does not provide impacts analyses specific to the Verde Valley.

Human Health

According to the Fourth National Climate Assessment, changes in climate are already affecting the health and well-being of people across the country, and adverse health consequences are projected to worsen as temperatures continue to warm (Ebi et al. 2018). Children, older adults, and people with pre-existing conditions are particularly vulnerable to health impacts. Climate-related health risks include direct impacts from heat waves, floods, droughts, and wildfire, and indirect impacts from air quality, changes in vector-borne diseases, food security, and mental health. In this summary, we focus on heat, air quality, vector-borne diseases, and mental health.

Extreme Heat and Energy Use

Extreme heat places greater stress on the body, especially when combined with humidity and when nighttime temperatures don’t cool off enough to allow the body relief (Brown et al. 2013). Older adults, children, those who work outside, those with chronic illnesses, and those who are socially isolated tend to be at greater risk. Between 2003 and 2013, 1574 people in Arizona died due to exposure to excessive natural heat (Arizona Department of Health Services 2015). As temperatures rise, heat waves in the Southwest U.S. are predicted to become longer, more frequent, and more intense, which will increase the risk of heat-associated deaths (Gershunov et al. 2013). By 2050, based on a higher scenario (RCP 8.5), the Southwest is projected to experience an estimated 850 additional deaths per year with an associated economic loss of $11 billion (in 2015 dollars) from the loss of labor and productivity associated with loss of life (Gonzalez et al. 2018). By 2090, deaths and associated economic losses are projected to double from 2050.

Humans have been adapting to higher overall temperatures through a combination of improved social responses, physiological acclimatization, and technology (i.e., air conditioning) (Crimmins et al. 2016). Increased use of air conditioning (AC), because of higher daytime and nighttime temperatures and improved access to technology, will increase energy consumption. Due to the need for additional cooling, by 2080–2099, electric consumer energy will cost an estimated $164 million more per year in the state of Arizona, compared to 2008–2012; on a household basis, this equates to about $100 per household per year (Huang and Gurney 2017). Additionally, increased energy use can stress the electrical grid, increasing the risk for brownouts—a partial, temporary reduction in system voltage (Tidwell et al. 2013). Furthermore, if the energy comes from the burning of fossil fuels, then it will release more greenhouse gases, increasing temperatures further, which will in turn increase demand for AC, and so on (this is referred to as a positive feedback loop).

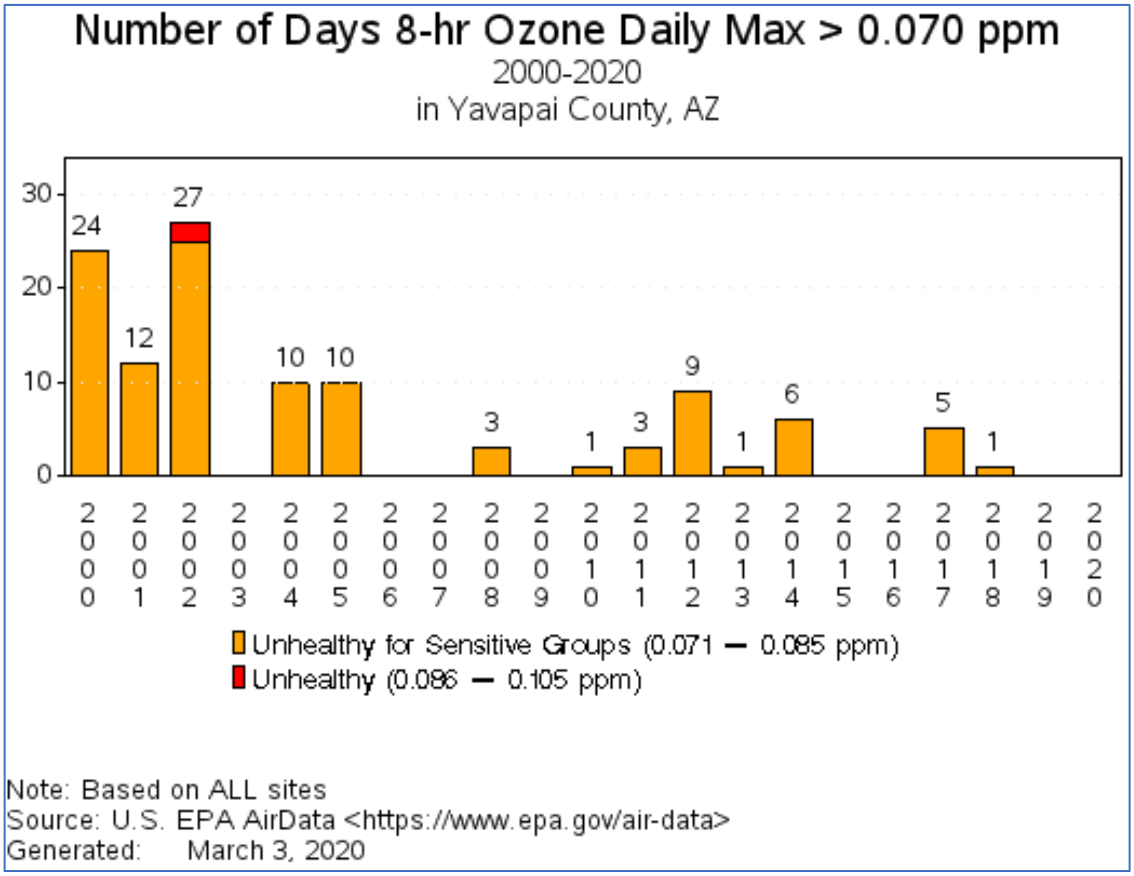
Air quality

Climatic changes are also affecting air quality, with implications for human health such as rising rates of asthma and other allergic diseases as well as respiratory diseases (Crimmins et al. 2016). Ground-level ozone pollution, fine particulate matter 2.5 (PM2.5; particulate matter smaller than 2.5

microns), and particulate matter 10 (PM10; particulate matter between 2.5 and 10 microns) are several of the air pollutants likely to be affected by climatic changes.

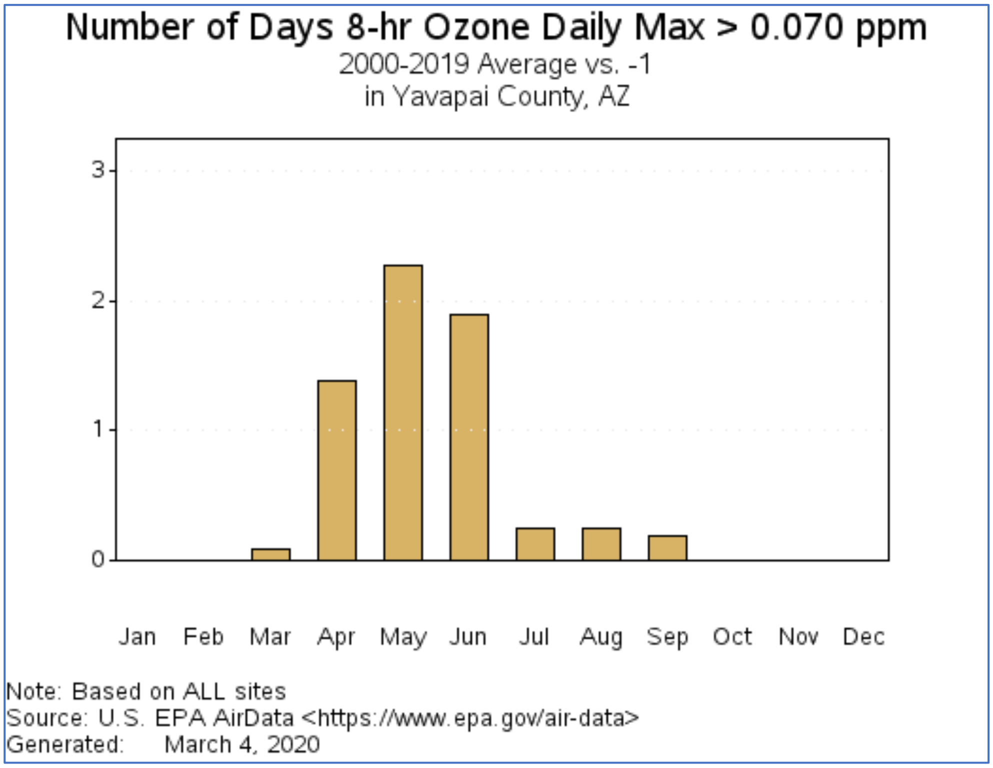
Increased temperatures will increase ground-level ozone pollution, which is produced when nitrogen oxides and hydrocarbons from automobile exhaust, power plant and industrial emissions, gasoline vapors, chemical solvents, and some natural sources react in heat and sunlight. Exposure to ground-level ozone is linked to reduced lung function and respiratory problems such as pain with deep breathing, coughing, and airway inflammation (Brown et al. 2013), which can contribute to increased deaths (Crimmins et al. 2016).

Ozone exceedance days have fallen in Yavapai County (station located near Prescott) since the early 2000s (Figure 22). However, ozone in Yavapai County tends to peak in the hotter months preceding the monsoon season – April through June (Figure 23). As temperatures rise and heat waves become more common, ozone exceedance days may also rise.



Note: Based on ALL sites
Source: U.S. EPA AirData <https://www.epa.gov/air-data>
Generated: March 3, 2020

Figure 22: Number of days ozone levels have exceeded 0.07 parts per million (ppm), which is unhealthy for sensitive groups, and 0.086 ppm, which is unhealthy for all.



Note: Based on ALL sites
Source: U.S. EPA AirData <https://www.epa.gov/air-data>
Generated: March 4, 2020

Figure 23: Average number of days from 2000 to 2019 in which ozone exceeded 0.070 ppm in each month. April - June, three of the warmest months, also had the highest number of high ozone days.

PM 2.5 is often generated by vehicle exhaust and power plant emissions (Environmental Protection Agency 2013). Another source of PM 2.5 is wildfires, which are expected to become larger and more frequent as climate conditions become hotter and drier (see the section on Wildfires on page 33). The smoke from wildfires can travel and affect air quality thousands of miles away, such as when smoke from the 2011 Wallow Fire spread into Texas and Oklahoma from Arizona. High levels of PM 2.5 are associated with mortality related to cardiovascular problems, particularly among the elderly, and reduced lung function and growth, increased respiratory stress, and asthma in children (Brown, Comrie, and Drechsler 2013).

In Yavapai County, PM10 pollution often comes in the form of dust. In Central Arizona, dust storms tend to peak during the winter months, as Pacific storms bring gusty winds causing localized blowing dust from single point sources such as degraded desert, abandoned farmland and dirt roads (Figure 24) (Lader et al. 2016). Dust storms have been occurring more frequently and over a longer season in recent years in Arizona due to drought conditions (Tong et al. 2017). The decade of the 2000s saw significantly more dust storms than the 1990s (Figure 25) (Tong et al. 2017). Dust can enter the nose and lungs and create serious health problems.

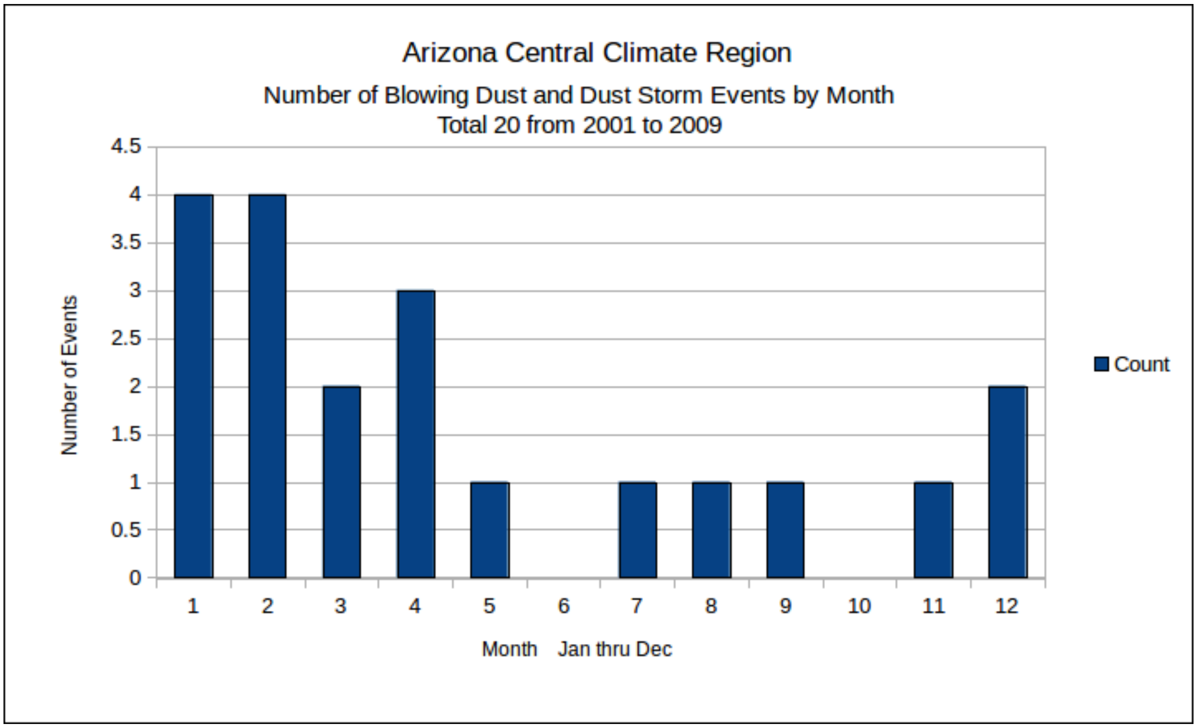


Figure 24: Monthly frequency of blowing dust and dust storms in the Central climate region, including most of Yavapai and Gila Counties, from 2001-2009.

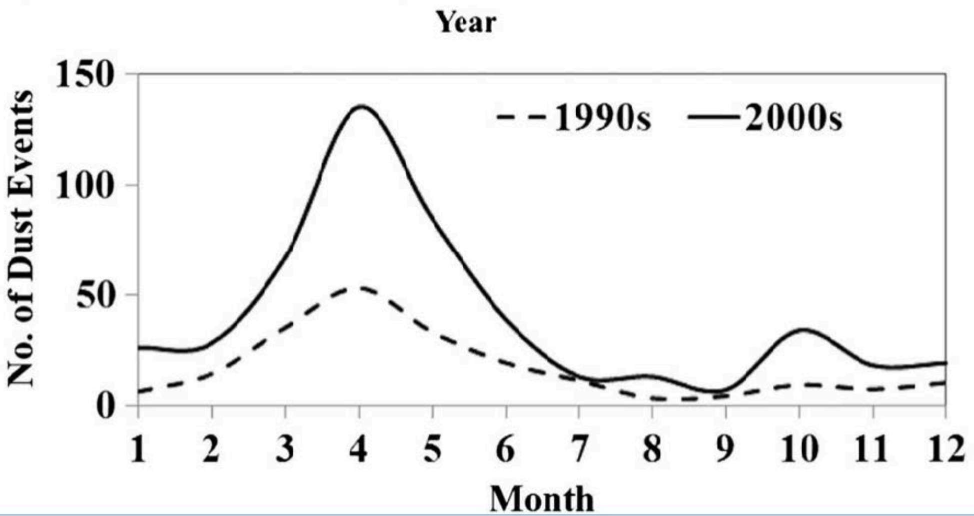


Figure 25: Monthly distribution of dust events across the western United States in the 1990s and 2000s.

Vector-borne diseases

Climate change seems likely to affect certain vector-borne diseases like West Nile Virus (WNV), because warmer temperatures will create a more welcoming environment for the mosquitos that carry WNV. The mosquitos that carry WNV are the *Culex tarsalis* and *Culex quinquefasciatus*. Climate change is likely to lengthen the season during which mosquitos can survive and breed. However, in some areas, extreme temperatures in mid-summer (over 104° F) may be high enough to substantially reduce mosquito populations during the hottest months. In other words, the mosquito season may expand, but there may be a reduction in the number of mosquitos during the hottest months of the year in the future. However, mosquito populations may rebound once temperatures cool in the late summer and early fall – so the reduction may be temporary and only occur in areas with extreme summer temperatures (Roach et al. 2017).

Valley fever (VF) is another vector-borne disease that is at least partially influenced by climate and weather conditions. Predicting changes in VF prevalence due to climate change is challenging because there are many factors involved. The highest incidence (cases/population) tend to occur in more populated counties. Age seems to be a risk factor, as is working outdoors. VF tends to occur when conditions are first moist, then hot, dry, and windy, which allows the fungus to grow and then become aerosolized. It seems that the timing of these events is critical as well as the direction of the wind: from places where the fungus grows to places where the population is at risk. However, because the exact location of the fungus in the soils is unknown, it is difficult to predict if and when it might affect specific communities now or in the future (Roach et al. 2017).

Mental health

Many people exposed to climate-related disasters, such as flooding, heat, and wildfire, experience serious mental health consequences, such as post-traumatic stress disorder, depression, and general anxiety, which often occur simultaneously. These consequences are especially true with events that involve "loss of life, resources, or social support and social networks or events that involve extensive relocation and life disruption" (Dodgen et al. 2016). Populations at particular risk of mental health consequences include children, the elderly, pregnant and post-partum women, people with preexisting mental illness, the economically disadvantaged, the homeless, and first responders.

Of particular interest in central and northern Arizona is the potential mental health consequences from relocation due to wildfire. Additionally, clinical depression has been observed in patients infected with WNV (Dodgen et al. 2016). Some studies have shown a connection between higher temperatures and suicide rates (Gonzalez et al. 2018).

Ecosystem Impacts

Forest Health

Drought and rising temperatures affect forests in several ways. First, direct stress from heat and lack of moisture reduces tree growth and increases tree mortality (Williams et al. 2010). Second, insect outbreaks increase with warmer temperatures and drought-stressed forests are more vulnerable to those outbreaks. In mid-elevation conifer forests in the western U.S., the rate of tree death has doubled from 1955–2007 (Gonzalez et al. 2018). Bark beetle infestations killed 7% of western U.S. forest area between 1979 and 2012 (Gonzalez et al. 2018). Insect populations, such as mountain pine beetle and spruce beetle, are expected to increase as temperatures and the incidence of drought increase. However, there will be variability over time and geographic area (Bentz et al. 2010). While most research on temperature impacts and forest pests to-date has focused on the mountain pine beetle and spruce beetle, there are several species of aggressive bark beetles that are found in the types of forests near the Verde Valley. Western pine and mountain beetles are found in ponderosa pine, and piñon ips are found in piñon pines. A combination of warming temperatures, previous management practices such as fire suppression, natural disturbances, and other human influences such as pollution are responsible for current outbreaks and will continue to be factors in future outbreaks, particularly as temperatures warm (Bentz and Logan 2009).

Wildfires

Warming is already driving an increase in the area burned by wildfires as well as an expansion of the fire season (Westerling et al. 2006). These trends are expected to continue with increased warming in the future.

From 1984–2015, the area burned by wildfire was approximately 24 million acres, twice what would have burned without climate change (about 12 million acres) (Figure 26) (Gonzalez et al. 2018). The effects of warming are exacerbated by insect outbreaks, human settlements, and the 20th century policy of fire suppression, all of which contribute to increased fire risk in southwestern forests (Abatzoglou & Williams, 2016).

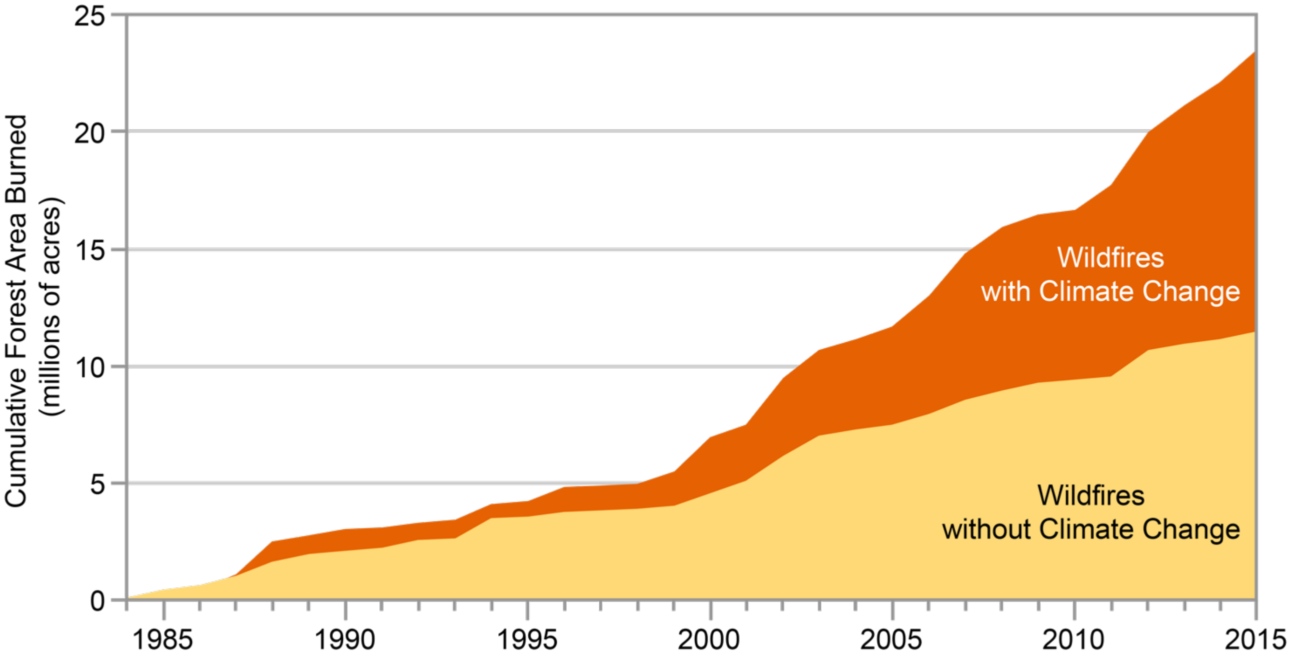


Figure 26: The cumulative forest area burned by wildfires has greatly increased between 1984 and 2015, with analyses estimating that the area burned by wildfire across the western United States over that period was twice what would have burned had climate change not occurred. Source: Figure 25.4 from Gonzalez et al. (2018); adapted from Abatzoglou and Williams (2016).

Given climate change projections, substantial increases in the area burned by wildfires are projected in the future as well (Hurteau et al. 2014). The National Research Council (2011) estimates a 380% increase in area burned in the Southwest with a 1° C (roughly 2° F) increase in average temperatures. Under higher emissions scenarios, fire frequency could increase 25% and the frequency of very large fires (greater than 12,000 acres) could triple (Gonzalez et al. 2018). In addition to the effect of the warming trend, human-caused fires are also increasing. The majority of contemporary fires in the United States are human-started; for the period of 1992–2013, 84% of ignitions were human-caused (Balch et al. 2017), and that rate is increasing (Cattau et al. 2020). However, lightning-caused fires are still more common in the Southwest (Balch et al. 2017).

In specific areas, the occurrence of larger, more frequent fires may be tempered if fuels are less available or flammable in any given year (due to drought or past fires, for example) (Littell et al. 2018). Despite the overall trend in larger, more frequent fires, there will still be year-to-year variability in fire events.

The anticipated increase in the number of fires and acres burned means rising costs. Cumulative firefighting costs in the Southwest could total $13 billion from 2006 to 2099 (in 2015 dollars) (Gonzalez et al. 2018).

Flooding

Although overall precipitation may remain steady or decline slightly, individual precipitation events may become more extreme because a warmer atmosphere holds more water (Gershunov et al., 2013). Changes to the North American Monsoon and atmospheric rivers are also changing the rates of extreme precipitation (see section on Changes in Character of Precipitation on page 23). Areas in and around the community that are already flood-prone may experience larger floods, such as development near rivers, creeks, and washes. Areas that do not regularly flood now could become flood-prone with larger storm events.

Post-fire flooding

The combination of more frequent, larger forest fires and more extreme precipitation can lead to more post-fire flood events, although post-fire debris flows can occur with relatively “normal” storms (Garfin et al. 2016). Post-fire floods can decrease water quality by pushing sediment into water sources, with effects lasting up to 10 years after the fire. Neighborhoods and community water systems in the wildland-urban interface (WUI) may be at greater risk from wildfire and post-fire floods/debris flows (Garfin et al., 2016).

Post-fire floods can also impact streamflow by changing the geomorphology of a basin, create hazards because of debris flows on roads, houses, and other infrastructure, and damage ecosystems by eroding and denuding landscapes.

Drought

Even without changes to annual average precipitation, rising temperatures are likely to make drought conditions worse because of increased evaporation of water from surface sources and transpiration from plants. Both streamflow levels and soil moisture levels (both of which can be used as drought indicators) are likely to be impacted.

One way to assess potential future drought impacts is to look to paleoclimate records to understand past conditions. Tree ring records can be used to track past climate variability by examining the size and timing of growth rings. In the Southwest, these tree ring records indicate that in the past, droughts lasting multiple decades (termed “megadroughts”) have occurred in this region, with aridity as bad or worse than the worst droughts of the 20th century.

Historically, these megadroughts, lasting at least 35 years, occurred about once or twice per thousand years. If temperatures rise by more than 9° F (5° C), the risk of megadrought in the Southwest will be almost 100% by 2100 (Ault et al. 2016). Megadroughts could occur an average of once every 200 years, based on moderate and high emissions scenarios (RCPs 4.5 and 8.5) (Ault et al. 2014). Shorter, but still significant, droughts lasting at least 11 years could occur 1.5 to 1.75 times per 100 years under all future emissions scenarios.

Water Resources

Climate change is affecting water resources by changing streamflow patterns, contributing to reductions in water availability, and contributing to poorer water quality.

Streamflow

Even without a reduction in total precipitation, streamflow patterns are changing as warmer temperatures lead to earlier snowmelt, more rain and less snow, increased dust-on-snow events, and changes in storm tracks (Udall 2013). In the intermountain region of the western U.S., total snowfall is projected to decrease due to warmer winters, which will change more snow events into rain events. The amount of water stored in snowpack (snow water equivalent) in the western U.S. decreased 10-20% between the 1980s and 2000s and is projected to further decrease by 60% in the next 30 years (Fyfe et al. 2017). In northern Arizona, April 1 snow water equivalent is projected to decline by approximately 40% by 2041–2070 (Cayan et al. 2013). However, extreme snowfall events (much greater than average) are projected to increase in some areas (note this is similar to projections in rainfall, with precipitation falling in fewer but more extreme storms). When snow does fall, the warmer temperatures mean the snow will likely be denser (warmer and more likely to melt), the period of snow cover will be shorter, and there will be greater potential for rain-on-snow events, which speed snowmelt and runoff.

Dust from human activities, and exacerbated by drying soils, that falls on top of snowpack, speeds up the melting process. This is because the dust absorbs relatively more sunlight and heat than clean snow with its higher reflectivity, or ***albedo***. In addition to the overall warming trend, dust on snow is leading to earlier (and faster) melting. The result is that more snow will melt earlier in the spring, increasing streamflow at that time of year and reducing flows in late-spring and summer (Cayan et al. 2013). The figure below (Figure 27) displays the average streamflow projections for the decades 1990s, 2020s, 2050s, and 2070s from a Bureau of Reclamation Colorado River Basin study (U.S. Department of the Interior Bureau of Reclamation 2016). When compared to the 1990s (black line), a reduction in streamflow becomes evident in the 2050s (green line) and both a reduction in streamflow and change in peak flow timing are evident in the 2070s (red line), with flows starting to peak in May instead of June but being lower than in past decades.

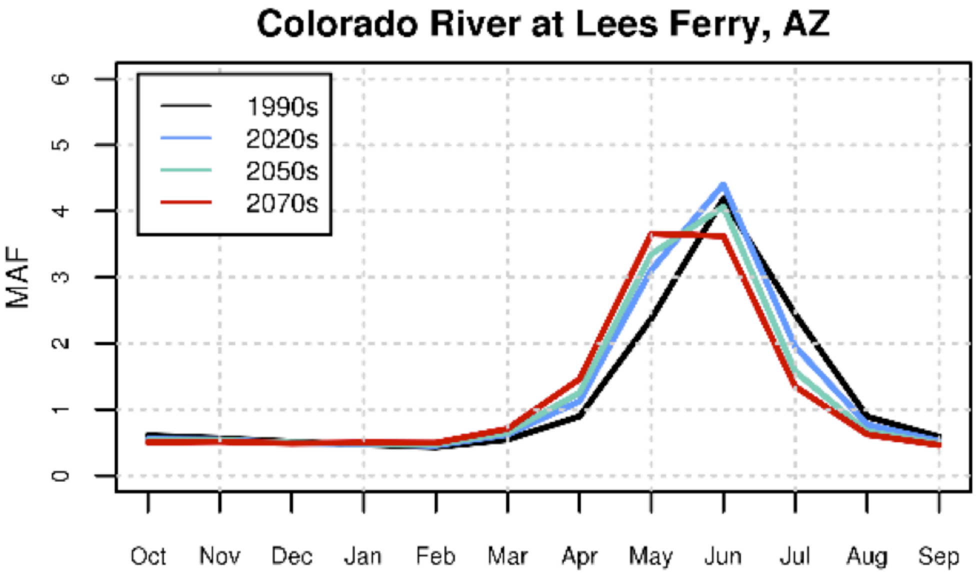


Figure 27: Projected streamflow for the Colorado River at Lees Ferry, AZ. Source: (U.S. Department of the Interior Bureau of Reclamation 2016)

Water Availability

The Colorado River is the primary source of water for much of Arizona. However, flows in the river are being negatively affected by climate change, with implications for water availability throughout the state. Studies of the Colorado River indicate that, for every 1° F of warming, there is a decrease in streamflow at Lees Ferry (where Colorado River Flows are measured) of 2.8-5.5% (Udall 2013).

These changes to the amount of runoff in the Colorado River system are in addition to a pre-existing stressor: the river is over-allocated and in a structural deficit stemming from a combination of losses from evaporation and water use (Central Arizona Project 2015). The water usage in the lower basin—Arizona, California, and Nevada—is 1.2 million acre feet (MAF) greater than the inflows to Lake Mead that supply the region.

Water levels in Lake Mead have been dropping since 2000 (Central Arizona Project 2015). To address the deficit, in 2007 the lower basin states agreed to a set of interim guidelines intended to run through 2026. These guidelines were designed to provide greater certainty for water users during times of shortages in Lakes Mead and Powell by creating a series of thresholds and related reductions to water deliveries to guide decisions about water delivery (Jerla and Prairie 2009). The delivery reductions will take place when the water level in Lake Mead reaches three different thresholds: 1,075 feet above mean sea level (amsl), 1,050 amsl, and 1,025 amsl. One thousand feet amsl is considered the critical level for Lake Mead when both water and energy availability are at risk. If Lake Mead falls to the critical 1,000 feet amsl level, the Secretary of the Interior will consult with the basin states to discuss further measures. Each threshold will trigger a tier reduction.

- A Tier 1 reduction requires Arizona to reduce Central Arizona Project (CAP) water deliveries by 320,000 AF per year. At this level, the CAP will make cuts to the excess storage deliveries and the agriculture pool.
- A Tier 2 reduction requires 400,000 AF of reductions each year to the excess and agricultural pools.
- A Tier 3 reduction will require 480,000 AF of reductions in Arizona but will not impact Municipal and Industrial or Indian Priority deliveries.

The first shortage declaration, at the Tier 1 level, is expected in 2022. In response, the Colorado River basin states have prepared The Colorado River Drought Contingency Plan (DCP) intended to prevent the kinds of cuts required by a Tier 2 shortage (Lake Mead reaching 1050 feet amsl). Arizona's portion of the DCP relies on voluntary cuts to CAP water use by farmers, who will receive financial support to help them switch to groundwater for irrigation; payments to the Gila River Indian Community and Colorado River Indian Tribes in return for them leaving water in Lake Mead; and some loosening of Arizona's groundwater management rules. The DCP was signed in May 2019.

Verde River

Currently, diversions of Verde River surface water are largely unregulated, which reduces river flow, especially in the summer when the river often runs dry (Douglass-Gallagher and Stuart 2019). By 2050, projections indicate a potential 23% reduction in runoff from the Salt/Verde river system with a worst-case reduction of up to 50% (Bolin, Seetharam, and Pompeii 2010; Gober et al. 2010). Annual zero-flow days are projected to increase by 27% by midcentury, and stream drying events are projected to be longer and more frequent. In spring and early summer, flowing portions of the Verde watershed could decrease by 8-20%, with longer stretches of dry channel fragments. These changes have large implications for native fish and other plant and animal species, as available seasonal habitat disappears (Jaeger, Olden, and Pelland 2014).

The population of Yavapai County is estimated to more than double by 2050, creating an unmet water supply demand of almost 50,000 acre feet/year (Douglass-Gallagher and Stuart 2019). An additional stressor on the Verde River system is water demand from the Phoenix Metropolitan area, which is growing as the population grows. Given future streamflow projections for the Colorado River Basin and potential shortages, the Salt River Project (SRP) diversifies its water supplies by pulling additional water from the Salt and Verde Rivers. Thus, there are many factors complicating water rights across the region, such as population demands from various municipalities, hydropower production, irrigation diversions, and pumping for agriculture (Serrat-Capdevila et al. 2013).

Water Quality

There are three main impacts to water quality from rising temperatures and changes in precipitation patterns: the effects of wildfires on surface water, the effects of drought, and the interaction between extreme precipitation and non-point source pollution. Wildfires, especially very large fires, can significantly alter landscapes and watersheds. When rainfall occurs up to a few years after a fire, erosion increases and changes in runoff greatly increase the amount of sediment that is transported downstream, in some cases increasing it up to 20 times normal levels (Garfin et al. 2016). Stormwater runoff from a burned area can also include higher concentrations of trace elements, organic carbon, pH and nitrates and sulfates (Smith et al. 2011).

More frequent and longer droughts, and associated low stream and reservoir levels, can increase the concentrations of nutrients in streams, such as ammonia and nitrate, potentially raising the likelihood of harmful algal blooms and low oxygen conditions (Geogakakos et al. 2014).

With higher temperatures, more precipitation falls as rain instead of snow, increasing the amount of pollutants that wash from the ground and paved services into streams and reservoirs as compared to what would derive through slow percolation from snowmelt (Geogakakos et al. 2014).

Agriculture

Water availability is also a potential concern for agriculture in the Verde Valley. Warming temperatures mean a need for more irrigation at a time when a growing population also places demands on regional water resources (Yavapai County Water Advisory Committee 2013). About 1% of Yavapai County is used for agricultural purposes.[6] Of the 821,929 agricultural acres in the county, most (96%) is pastureland (U.S. Department of Agriculture 2017). Despite this relatively small area, agriculture in the Verde Valley is considered an important part of the culture. A recent study of agriculture in the region noted, "The Verde Valley was selected for our study based on its unique agricultural, political, and cultural context. Agriculture is deeply tied to the culture of the valley. While there was a decline in agriculture through the 20th century, more recently there has been an agricultural renaissance" (Douglass-Gallagher and Stuart 2019). The most common crops are pecans, grapes, corn for grain, and vegetables along with livestock, particularly cattle. Ninety-four percent of farms in Yavapai County are family farms (U.S. Department of Agriculture 2017).

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[6] The USDA does not report agricultural statistics for areas smaller than county scale.

In addition to water availability, risks to agriculture from regional warming include heat impacts to crops and livestock and damage to crops from wildfires (through smoke taint and insect displacement). Rising temperatures are likely to result in a longer growing season (Figure 21). Warmer temperatures in general advance the timing of growth stages of crops during the year (Brown 2013), which can affect planting and harvest timing. Excessive heat can also cause plants to slow or even stop photosynthesis, effectively delaying plant phenology and harvests (Morales-Castilla et al. 2020).

The increased warmth may increase pest persistence and allow new pests to become established in the region (Frisvold et al. 2013). Warming and drying may negatively impact rangeland conditions and available forage, and lead to pressures to buy additional feed, reduce herd size, lease additional grazing land, or overgraze rangeland (Frisvold et al. 2013). In addition, hotter temperatures can increase the heat stress on livestock and contribute to disease proliferation (Hatfield et al. 2014; Gaughan et al. 2009).

Another agricultural concern in the Verde Valley is impacts to pecans and winegrapes. Pecans are at risk of vivipary, or germination of the nut prior to harvest (Call, Gibson, and Kilby 2006). This disorder causes the nut to lose flavor and result in lower market value or crop loss. While not the sole cause, high temperatures and humidity levels in late summer and early autumn can lead to vivipary. There are orchard management actions through irrigation and nitrogen fertilization that can reduce the occurrence of vivipary (Wood 2015). The proposed Verde Valley American Viticultural Area is already a relatively warm region for viticulture (https://cals.arizona.edu/research/climategem/content/arizona-avas). Further increases in temperature during late summer months may increase detrimental impacts from excessive heat on ripening fruit and the resulting wine (De Orduña 2010). Although a small risk because the timing of wildfires and the ripening and harvest period for winegrapes do not tend to overlap in Arizona, smoke taint (which can cause undesirable wine flavors and aromas) from wildfires can occur if wildfires persist into late summer.

Climate Change Adaptation Planning

Climate change adaptation planning is the process of planning to adjust to new or changing environments in ways that take advantage of beneficial opportunities and reduce negative effects (Melillo, Richmond, and Yohe 2014).

The process of climate change adaptation planning can be similar to other resource management planning processes and generally includes the following steps:

- Identifying risks and vulnerabilities
- Assessing and selecting options
- Implementing strategies
- Monitoring and evaluating the outcomes of each strategy
- Revising strategies and the plan as a whole in response to evaluation outcomes

Figure 28: The Adaptation Process. Source http://nca2014.globalchange.gov/report/response-strategies/adaptation

Adaptation strategies can range from short-term coping actions to longer-term, deeper transformations. They can meet more than just climate change goals alone and should be sensitive to the community or region; there are no one-size-fits-all answers (Moser and Eckstrom 2010).

Key questions to ask community members, resource managers, decision makers, and elected officials when considering climate adaptation are:

- What are the community's goals and objectives in the future?
- What resources or assets need to be protected from climate change impacts?
- How will the resources be protected?
- What actions are necessary to achieve the community's goals?

The process of planning for climate change adaptation has already begun in many places. Seventeen states and approximately 200 cities have climate change adaptation plans.

Climate Adaptation Strategies

In this section, we present suggestions for possible climate adaptation strategies for the City of Sedona and the Verde Valley. **The community should make decisions about which strategies will be most beneficial and effective**. We present these strategies as options that can be considered as part of the planning processes. We focus here on Wildfire, Flooding, and Agricultural strategies and provide examples to build upon.

Wildfire

Wildfire adaptation strategies include those related to emergency preparedness and individual risk reduction at the property level and those related to long-range land-use decisions that can increase or decrease a community's overall fire risk at the wildland-urban interface (WUI).

- For emergency preparedness, communities in the Verde Valley can continue and increase their participation in the Firewise USA program, which teaches residents how to adapt to living with wildfire and encourages community members to take action now to prevent future losses. Jerome and Verde Lakes are already Firewise communities. The Sedona Fire District and U.S. Forest Service have also promoted Firewise and have held an annual cleanup for residents.
- The City of Sedona has existing initiatives with the Sedona Fire District and the U.S. Forest Service for community education around WUI wildfire risk reduction. These can continue to be strengthened and integrated as appropriate into adaptation plans and existing land use and zoning regulations.
- Long-range land-use decisions also have an impact on wildfire risk, particularly as development encroaches upon previously forested and natural areas. Development pressures, as well as other community priorities such as increasing affordable housing, should be balanced carefully. Guidance on wildfire risk reduction can be found in the American Planning Association's Planning the Wildland-Urban Interface report, which discusses best practices for integrating wildfire protection into land-use regulations and long-range plans, including:
  - Utilize existing planning processes, such as updates to existing community plans, hazard mitigation plans, and wildfire protection plans, as opportunities to engage the community on long-range land-use decisions that may place more development in WUI areas and increase exposure to wildfire risk.
  - Balance affordable housing needs and wildfire risk if development is proposed in WUI areas and incentivize developments to occur in lower-risk areas, particularly within existing communities.
  - Review transportation plans and the accessibility of existing neighborhoods and developments to allow for quick and efficient evacuation.
  - Review and update subdivision regulations, zoning and land development codes, building codes, and applicable fire codes with increased risk of wildfire due to climate change in mind.
  - Review and update emergency management plans with increased risk of wildfire due to climate change in mind.
  - Ensure all stakeholders, such as the community, public health officials, land managers, utilities, and those currently working on wildfire risk reduction, are brought into future planning efforts to reduce wildfire risk.

- Use the Fire Adapted Communities Learning Network (FAC Net) self-assessment tool to
    - identify at-risk community values at risk,
    - identify capacity to implement activities,
    - assess gaps and limitations in funding, resources, and partnerships,
    - prioritize future actions,
    - complement other work plans, and
    - increase the community's awareness and understanding of community fire adaptation needs.

Flooding

Green infrastructure (GI) and low impact development (LID) are two well-established adaptation strategies to increase resilience to flood risk, and reduce reliance on scarce water resources for urban landscaping. The goal of both GI and LID is to "slow it [water] down, spread it out, and soak it in." The cost-benefits of GI and LID installation and maintenance are important for communities to weigh as they consider implementation options and funding mechanisms. The American Rivers' The Value of Green Infrastructure report and Urban Land Institute's Harvesting the Value of Water report both provide information on the economic, environmental, and social benefits and considerations. Values, such as gallons of water harvested in rainwater basins or reduced water treatment costs, can be quantified to show the impact of GI. Some other values, such as natural habitat increase or beautification of the landscaping, may be more difficult to quantify but should still be clearly articulated.

- Consider the use of common GI and LID design options such as bioswales, detention and retention ponds, porous pavements, and rainwater harvesting roadside curb cuts and gardens. When GI and LID are utilized in the Southwest, attention must be paid to our arid climate with high precipitation events, as well as the temperature differences between summer and winter.
    - Drought tolerant native plants that are low maintenance and can withstand normal temperature swings between hot and cold are the most ideal for GI and LID.
    - In areas with steeper slopes that may be more prone to erosion, GI should be designed differently than in flatter terrain.
    - Water harvesting basins in areas with steep slopes may not be feasible, but terraces, berms, and the use of porous materials can both slow and absorb water runoff.

- Urban forestry efforts to increase tree canopy can also have benefits of stabilizing soils, reducing flood severity, and providing shade, but should be considered strategically with water resources, maintenance costs, and wildfire risk in mind.
- Consult the American Planning Association Planning Advisory Services reports related to reducing flood risk through planning. The Planners and Water report uses the One Water approach to explore water supply, water quality, and stormwater as a single resource for planners to manage. The Subdivision Design and Flood Hazard Areas report offers practical local regulatory tools to review, inspect, and maintain flood risk across a variety of terrain and infrastructure needs, including:
    - Well-designed GI pilot projects with educational information in key areas to allow the public and stakeholders to observe the projects in a variety of conditions.
    - Identify flood-prone areas to prioritize the installation of GI along the public right-of-way.

    - Assess and update zoning regulations, engineering standards, and the stormwater management program as appropriate to allow for and incentivize GI and LID.
    - Update required and recommended plant lists with climate projections so that landscaping planted today is appropriate for changing conditions in the future. This information can also be distributed to local nurseries and landscape designers.
    - Urban forestry efforts should be coordinated with GI, particularly water harvesting basins, to allow for the increase of tree canopy and shade in appropriate locations while minimizing new water use needs.
    - Protect open space to minimize the increase of impervious surfaces and flood risk through the development of natural areas.
    - Avoid new development in flood-prone areas and consider future conditions of the floodplain, including both development impacts and climate change.

- Other resources for GI and LID appropriate for the City of Sedona and the Verde Valley include:
    - U.S. EPA's Green Infrastructure: Low-Impact Development and Green Infrastructure in the Semi-Arid West https://www.epa.gov/region8/green-infrastructure
    - U.S. EPA's Arid Green Infrastructure for Water Control and Conservation https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NERL&dirEntryId=325750
    - University of Arizona, Water Resource Research Center's Green Infrastructure for Southwestern Neighborhoods https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/WMG_Green%20Infrastructure%20for%20Southwestern%20Neighborhoods.pdf

- The National Flood Insurance Program (NFIP) allows property owners in participating communities to buy insurance to protect against flood losses. Participating communities are required to establish management regulations in order to reduce future flood damages. This insurance is intended to furnish as an insurance alternative to disaster assistance and reduces the rising costs of repairing damage to buildings and their contents caused by flood. Homeowners can determine whether their property lies in a flood-prone area by searching an online tool developed by the Federal Emergency Management Agency (FEMA). A challenge of the NFIP is that FEMA relies on historical flood data to determine 100-year flood plains. Although recommendations have been made to the agency to begin to incorporate climate change projections, they have not yet started the process. Additionally, most flood infrastructure is built with the 100-year historic flood as a reference. As storms are expected to become more intense, communities may consider reanalyzing existing drainage systems and washes to ensure that they can handle higher flood risk.

Agriculture

Adaptation options for agricultural producers include (Frisvold et al. 2013):

- Increasing crop diversity, such as introducing or increasing those better adapted to heat or with lower water requirements.
- Increasing yields through improved irrigation (e.g., drip over flood irrigation) and pest control practices.
- Diversifying income from both farm and off-farm sources.

- Participation in federal disaster relief programs when necessary.
    - USDA Farm Service Agency Disaster Assistance Program
    - Many ranchers work with the USDA Farm Service Agency (FSA) through the Disaster Assistance Program to help mitigate livestock losses during drought events.

- Livestock management strategies can help to reduce vulnerability, such as
    - Adjusting stocking rates
    - Implementing grazing management practices
    - Employing livestock bred for arid environments (i.e. Criollo cattle)
    - Erosion control along waterways
    - Use of alternate forage supplies

Farmers and ranchers in the Verde Valley are already finding ways to adapt to rising temperatures and reductions in water availability by changing the crops grown, installing drip irrigation where possible, storing rainwater, changing watering schedules, dry farming, and switching from surface water to groundwater (Douglass-Gallagher and Stuart 2019). For instance, some growers consider a conversion to vineyards as a response to decreasing water resources as winegrapes require less water than many crops presently grown in the valley.

Plan Implementation

Climate adaptation planning can present opportunities for collaboration across traditional department silos and various government agencies and community organizations. While these efforts can require more time for coordination and resources, it can also create potential efficiencies and partnerships when areas of common interest are found. Consider potential partners interested in advancing climate adaptation strategies including natural resource managers, emergency managers and hazard mitigation planners, first responders, public health agencies, environmental organizations, faith-based organizations, school districts, and private sector partners such as the land development community, construction industry, and planning and design consultants.

Climate adaptation strategies can be integrated into existing community plans, such as the *Sedona Community Plan* and hazard mitigation plans, or can be started as stand-alone adaptation plans. Regardless of approach, integrating adaptation considerations across all plans helps to ensure the various plans that reduce risk and guide future land uses are not in conflict with each other, and instead work together to move a community forward on its vision for its future. Beyond the Basics: Best Practices in Local Mitigation Planning provides an overview of considerations and several resources for integrated planning approaches for natural hazards. One key takeaway from the guide is the importance of reviewing the variety of plans that impact development holistically so that economic development goals in one plan do not encourage growth into areas identified as high risk in another plan. Well-developed implementation sections in plans can also increase their effectiveness. To be effective, implementation sections in plans should specifically identify:

- Adaptation strategies and actions
- Assign who (which agency or group) will be responsible for moving the strategy or action forward
- Timeline for actions
- Secured or potential funding sources
- Clear evaluation criteria, such as SMART (specific, measurable, attainable, relevant, and timely) indicators

- An assessment and update schedule for the plan

Revisiting the best-available data and evaluating the effectiveness of adaptation strategies regularly is necessary to ensure the overall effectiveness of plans and implementation efforts. There are no specific guidelines for updating adaptation-related plans, but a good frame of reference is that FEMA requires hazard mitigation plans to be updated every five years to ensure that data on hazards and vulnerabilities are kept up-to-date.

Additional Resources to Support Climate Change Adaptation Planning

The National Climate Assessment; Adaptation Chapter
http://nca2014.globalchange.gov/report/response-strategies/adaptation

Climate Adaptation: The State of Practice in U.S. Communities
http://kresge.org/climate-adaptation

Climate Adaptation Knowledge Exchange
http://www.cakex.org/

Lincoln Land Institute of Land Policy's Planning for Climate Change in the West
https://resilientwest.org/2017/planning-for-climate-change-in-the-west/

Urban Land Institute – Developing Resilience Case Studies
https://developingresilience.uli.org/

Glossary

Albedo: The proportion of solar radiation that is reflected by a surface, as opposed to being absorbed by that surface. Fresh snow has a relatively high albedo, because it is a light-colored surface and has high reflectivity.

Aspect: A surface feature of land: the direction a slope faces. A slope's aspect determines the amount of sun exposure it receives, so aspect affects temperature, humidity, and the type and amount of vegetation in a particular place.

Climate: The averages and patterns of weather over time for a particular area, such as temperature, precipitation, humidity, and wind.

Climate projections: Estimates of future climatic conditions, usually made with mathematical models using different rates of greenhouse gas emissions to create different possible future scenarios.

Climate trends: Changes in climate in a particular area that have been observed over time, such as increases or decreases in average temperatures or the amount of annual precipitation.

Downscaling: Various methods that use data from global climate models to derive climate information for smaller areas of the world, such as specific regions (U.S. Southwest, for example).

Greenhouse gas (GHG): Any of the atmospheric gases that absorbs longwave, or infrared, radiation that otherwise would pass from the Earth's surface through the atmosphere and into outer space. They include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2), and water vapor.

Magnitude of change: In climate models, the magnitude of change is how much the climate is projected to change over a given period of time. Climate scientists generally have more confidence in models' ability to project the *direction* of change, such as whether it will be hotter in the future; but not exactly how much hotter it will be.

Pluvial: A period of time, often multiple years, in which a particular area experiences abundant or well-above average precipitation.

Representative Concentration Pathways (RCP): Scenarios of different levels of greenhouse gas emissions that are used to estimate future global temperatures. The four RCPs used by the Intergovernmental Panel on Climate Change are 2.6, 4.5, 6.0, and 8.5; the numbers represent changes in radiative forcing, or the amount of outgoing infrared radiation relative to incoming shortwave solar radiation, at the top of the atmosphere.

Scenario: A description of a possible future state of the world. Scenarios do not represent what will happen; they represent what could happen, given our activities and choices.

Statistical downscaling: Correlating historical local and regional observations with data from global climate models to derive climate projections at local and regional scales.

Variability: A term to describe year-to-year changes in climatic conditions such as annual temperature and precipitation.

Weather: The day-to-day conditions in a particular area, such as temperature, precipitation, humidity, and wind.

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Links to Online Resources

PRISM dataset (p.11): http://prism.oregonstate.edu/

LOCA dataset (p.17): http://loca.ucsd.edu/

Climate Explorer (p.17): https://crt-climate-explorer.nemac.org/

Firewise (p.40): https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Firewise-USA/Become-a-Firewise-USA-site

Planning at the Wildland-Urban Interface (p.400: https://www.planning.org/publications/report/9174069/

Fire Adapted Communities Network (p. 41): https://fireadaptednetwork.org/

Planners and Water (p. 41): https://www.planning.org/publications/report/9131532/

Subdivision Design (p.41): https://www.planning.org/publications/report/9112664/

FEMA flood mapping (p. 42): https://msc.fema.gov/portal/home

Beyond the Basics (p.43): http://mitigationguide.org/