Climate Profile for
THE QUAD CITIES REGION OF ARIZONA

Climate Profile for the Quad Cities Region of Arizona

Climate Assessment for the Southwest (CLIMAS)

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Preface

In early 2021, a group of citizens of the Quad Cities region sought to commission a study that would help our communities to better understand and prepare for the challenges posed by climate change in our area. Led by the Yavapai Climate Change Coalition (YCCC), the PROTECT campaign coordinated with the Prescott City Council and approached CLIMAS (Climate Assessment for the Southwest; https://www.climas.arizona.edu/), a team of social, physical, and natural scientists at the University of Arizona and New Mexico State University that works with partners across the Southwest to increase resilience to regional climate change. On 24 May 2022, the Prescott City Council voted unanimously to commission the study, and in response to this local interest and support, CLIMAS offered to prepare the report. The report is funded, through CLIMAS, by the National Oceanic and Atmospheric Administration's Regional Integrated Sciences and Assessments (RISA) program through grant NA12OAR4310124.

Over the next several months, a broad-based working group of local stakeholders coordinated with CLIMAS to ensure that the Quad Cities' particular strengths and vulnerabilities to climate change were considered in the report, and this thoughtful input and review was vital to the report's final publication. The Working Group also contributed to the production of a companion document, Local Climate Action Options, hosted on the YCCC website, the Quad Cities Climate Action Hub (https://yavapaiclimatecoalition.org/climate-action-hub). This companion document is intended for use by Quad Cities communities, businesses, and individual citizens as a springboard to local climate actions across the region.

Our community is immensely grateful to CLIMAS for their expertise and generosity, to the Prescott City Council for their leadership and support, and to the organizations and individuals comprising the Working Group as listed below.

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Climate Profile 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.

This climate profile has been created for the Quad Cities region of Arizona (comprising Prescott, Prescott Valley, Chino Valley, and Dewey-Humboldt and the rural areas between them) using the boundaries of the Prescott Active Management Area. The Quad Cities region 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 average temperature for the Quad Cities area for the reference period 1961 – 1990 was 53.9° F. However, almost every year since 1985 has had annual average temperatures over this long-term average.
- These trends are projected to continue into the future. Average annual temperatures could be 5° F warmer (about 59° F) by 2050 and more than 11° F warmer (65° F) if we follow the higher greenhouse gas emissions scenario.

Extreme temperatures

- Between 1961 and 1990, the Quad Cities area averaged 8 days per year where high temperatures reached above 95° F. Recently, the area has seen about 20 days per year over 95° F. The projected change in the number of days above 95° F by 2100 ranges from 35 to 40 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 Quad Cities area could experience as few as 55 days per year that reach freezing temperatures (compared to the 1961 – 1990 average of 133 days per year).

Precipitation

Average precipitation

- The average annual precipitation in the Quad Cities area for the 1961 – 1990 reference period was 18.2 inches.
- Precipitation in this region is naturally variable from year-to-year. There is no clear trend toward changes in *average* precipitation amounts in the Quad Cities region. We expect this natural year-to-year 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, less surface water, reduced aquifer recharge, and will contribute to more frequent and severe drought.

Extreme precipitation

- As the atmosphere warms, it will be able to hold more moisture, which will produce more extreme precipitation even if the average amount of precipitation does not change very much.
- Another change in the character of precipitation is the frequency at which it falls. By 2050, the Quad Cities area could have an additional 10 days without precipitation (both the lower and higher scenarios). By the end of the century, dry days are projected to be approximately 275/year (lower scenario) to 285/year (higher scenario).
- Therefore, while the overall average amount of precipitation may not change substantially, the Quad Cities area may receive that precipitation in fewer, but more extreme storms.

Impacts

Human Health

- Extreme heat can affect human health, especially in vulnerable populations such as older adults, children and those with chronic illnesses. Extreme heat can also strain energy grids as residents increase their use of air conditioning to stay cool.
- Higher temperatures, smoke from wildfires, and dust storms all contribute to poor air quality and can create serious health problems, especially in vulnerable populations.
- Climate change may affect certain vector-borne diseases including West Nile Virus because warmer temperatures will create a more welcoming environment for the mosquitoes that carry West Nile Virus.
- Many people exposed to climate-related disasters such as flooding, heat, and wildfire experience serious mental health consequences such as post-traumatic stress disorder.

Forest Health

- Heat stress, lack of moisture, and increased insect outbreaks are all climate-related threats to forest health.
- Trees under stress from heat and drought are less able to defend themselves from insect outbreaks.
- All three stressors are already contributing to tree mortality in Southwestern forests, including those in the Quad Cities region.

Wildfire Risk

- Warming is already driving an increase in the area burned by wildfire as well as an expansion of fire season; this trend is expected to continue as temperatures rise and drought conditions persist. Fire frequency could increase 25% in the Southwest and the frequency of very large fires (over 12,000 acres) could triple.

- Communities in the wildland-urban interface are at particular risk from increased fire frequency and size.
- According to FEMA, the highest natural hazard risk to residents in Yavapai County as a whole is from wildfire.

Flooding

- The risk of flooding increases along with the risk of more extreme precipitation events. Areas that are already flood-prone may experience larger and more frequent floods and areas that do not regularly flood now may begin to flood as flood plains change due to extreme precipitation.
- Yavapai County is at a relatively high risk for riverine flooding at present.
- Extreme precipitation after wildfire events (post-fire flooding) can cause debris flows, decrease water quality, and even change the geomorphology of a basin.

Water Resources

- As the character of precipitation changes in the Quad Cities area it may see lower rates of aquifer recharge (like other areas in the Southwest). The Quad Cities area relies on groundwater for municipal, residential, and agricultural needs but current groundwater pumping often exceeds recharge rates. A further reduction in aquifer recharge due to climate change poses a risk to water resources in the area.

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 hazard mitigation plans, land use plans, or municipal strategic plans.
- Climate change adaptation plans can also be stand-alone plans – but communities should take care to ensure that adaptation plans and other community planning efforts are coordinated.
- Adaptation planning is a community-driven process in which community members and leaders should identify and discuss community values, goals, and capacities.

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 Quad Cities region of Arizona (comprising Prescott, Prescott Valley, Chino Valley, and Dewey-Humboldt and the rural areas between them) using the boundaries of the Prescott Active Management Area (see Figure 1). We used both observed climate and weather data as well as computer model projections of future climate for this analysis.

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

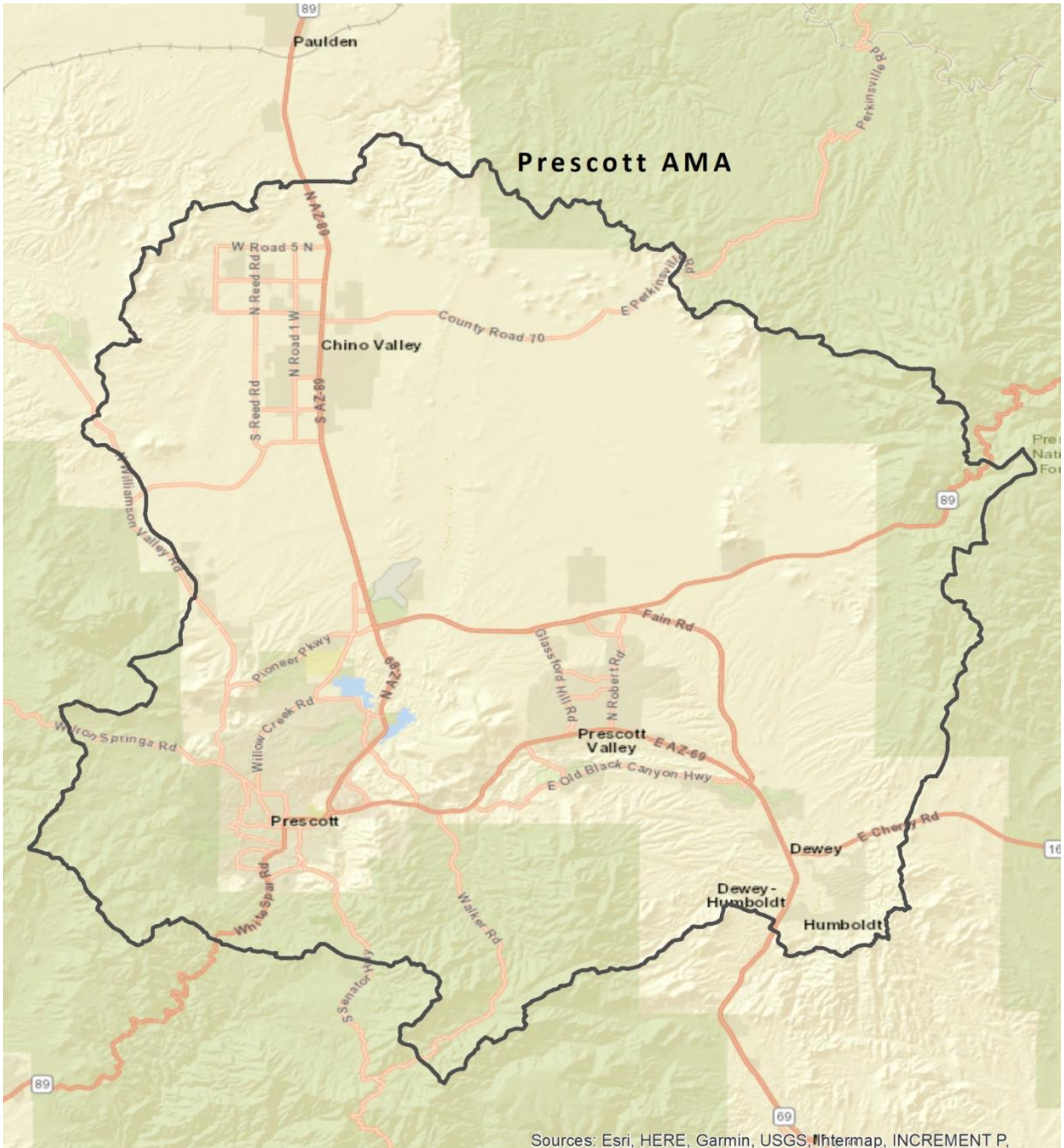

Figure 1: Prescott Active Management Area as defined by Arizona Department of Water Resources. This is the region selected for the climate analysis presented in this report.

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.

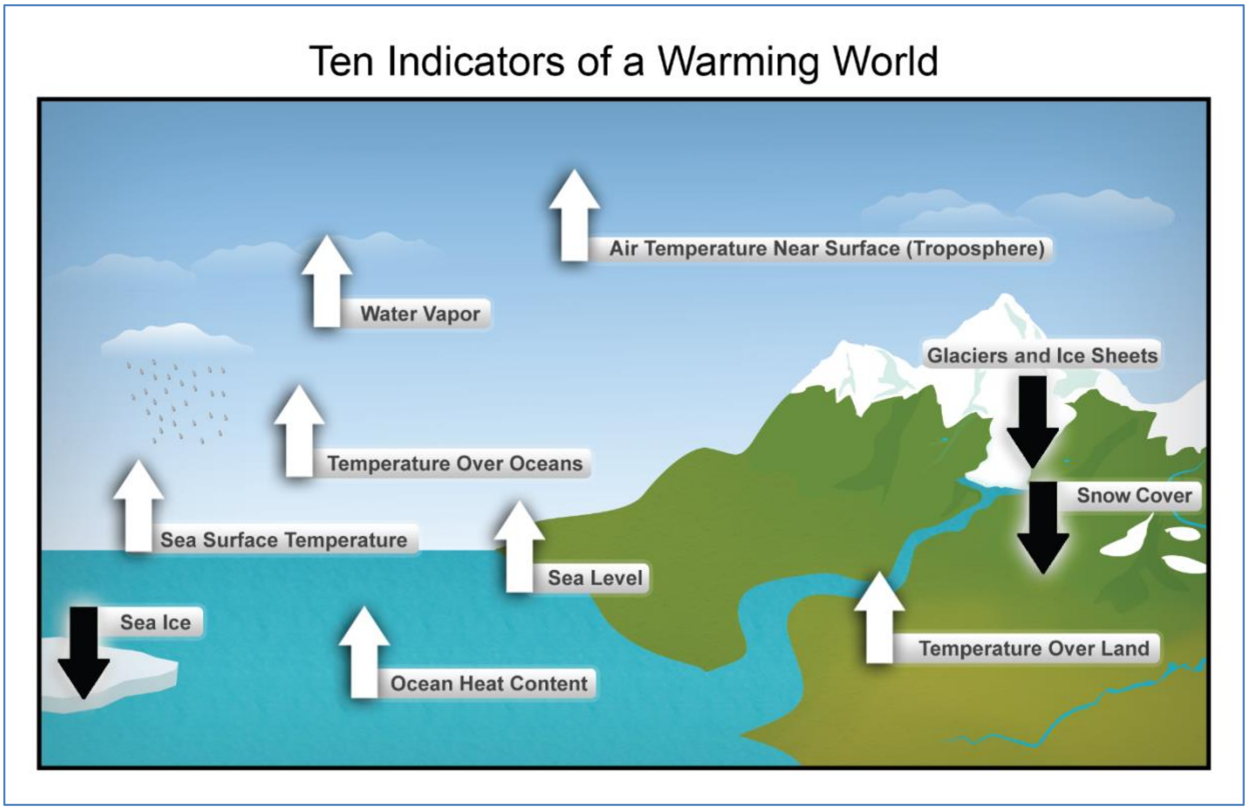

Figure 2: Observed indicators of a warming world. White arrows indicate increasing trends. Black arrows indicate decreasing trends. Source: http://nca2014.globalchange.gov/report/our-changing-climate/observed-change#tab2-images.

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.

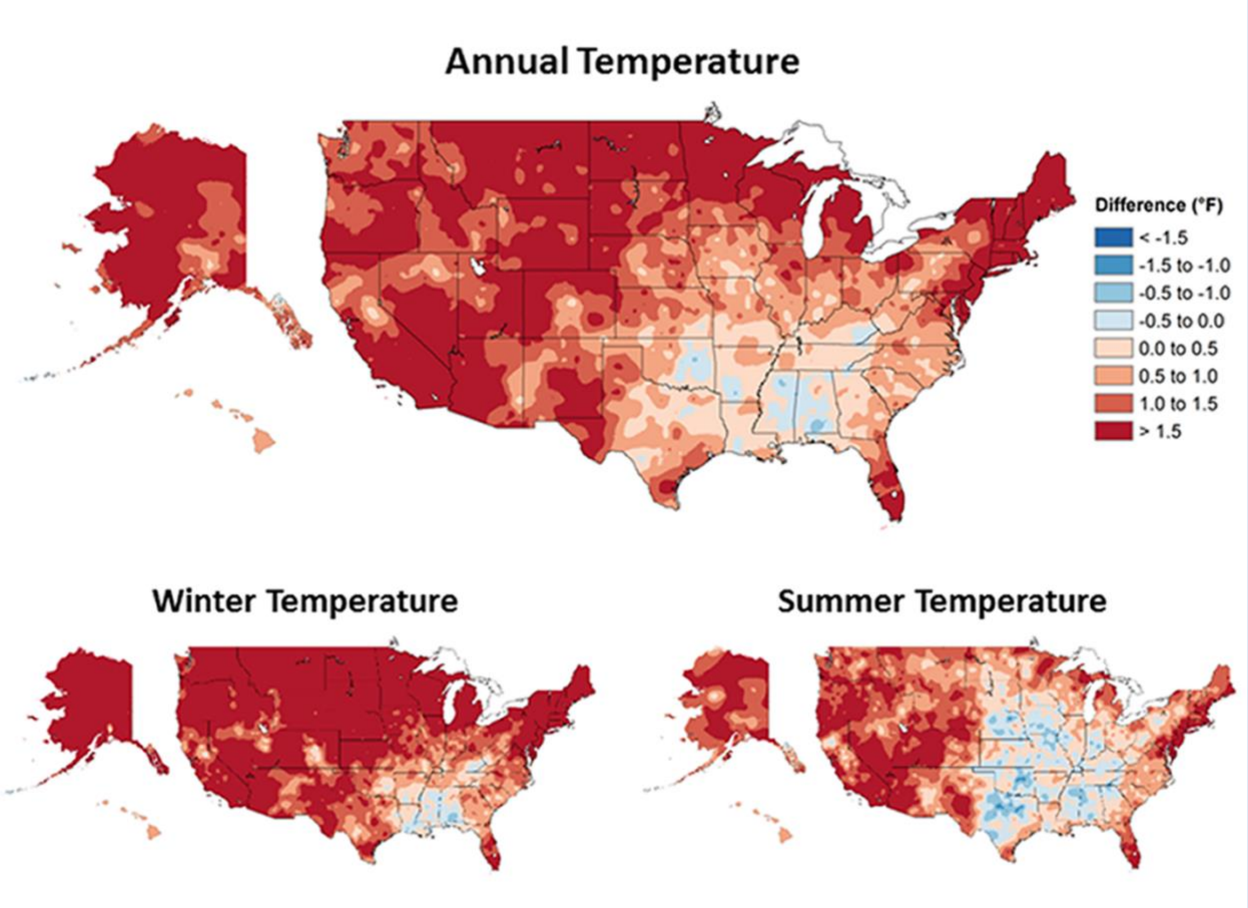

Figure 3: Observed temperature changes in the U.S. comparing the current period (1986 – 2016) to the period 1901–1960. The darker the color, the greater the difference between 1901–1960 and 1986 - 2016. Source: Climate Science Special Report: https://science2017.globalchange.gov/.

Why is the climate changing?

The sun's energy comes to 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 primarily 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.

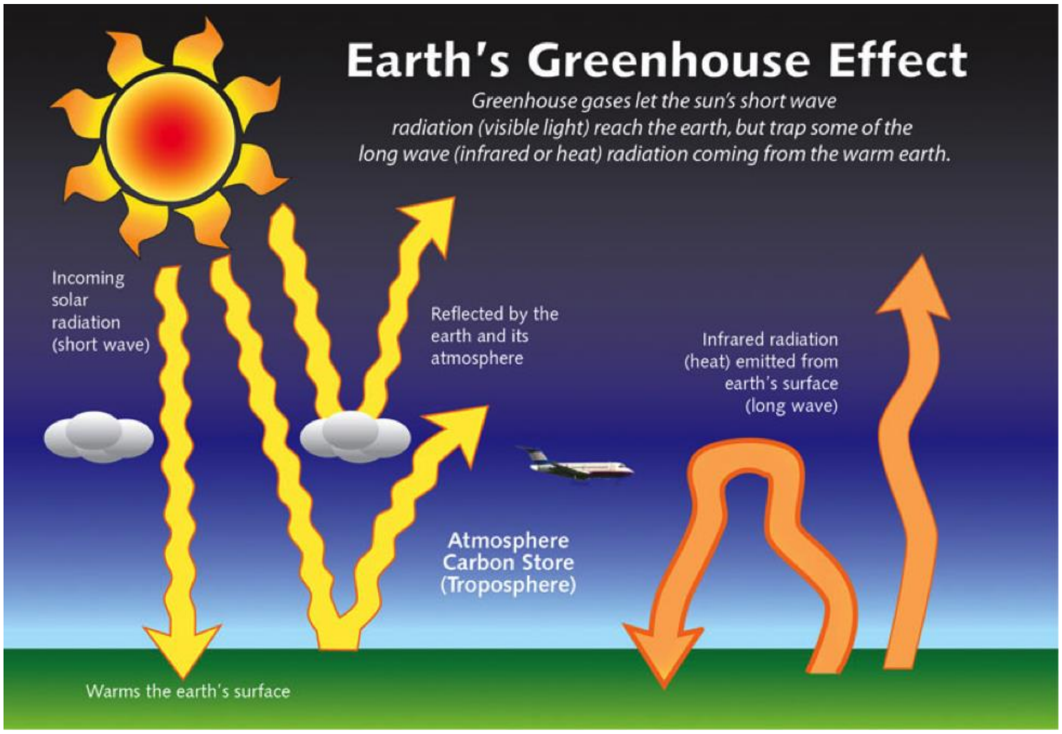

Figure 4: The Greenhouse Effect. Source: New York State Department of Environmental Conservation.

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 (instrumental record since 1880) 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)***. These variations can cause global temperatures to rise quickly during El Niño years and cool during La Niña years.

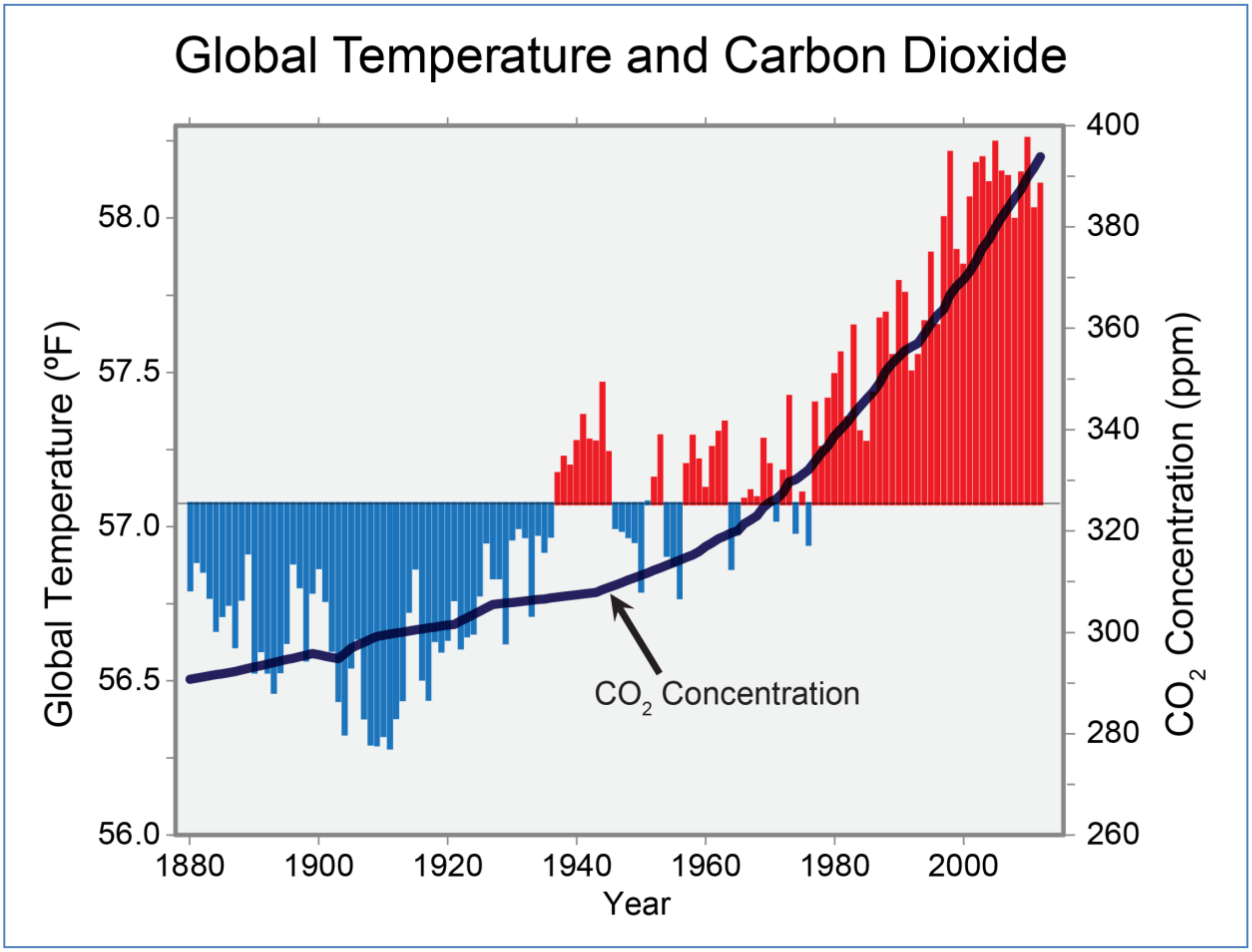

Figure 5: The corresponding rise in CO2 and global temperatures. Source: http://nca2014.globalchange.gov/report/our-changing-climate/observed-change#tab2-images

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 or the effects of 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.

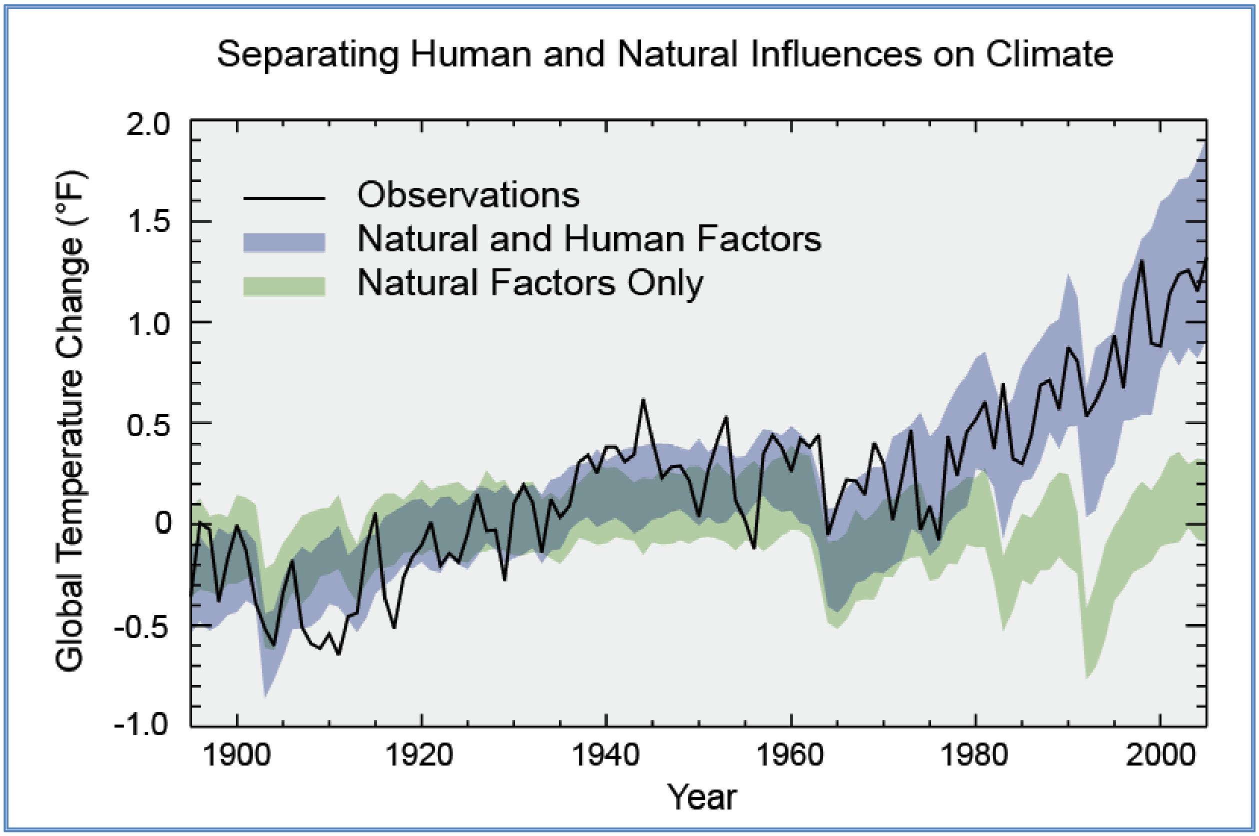

Figure 6: Results from a model experiment to compare natural warming factors with observed temperature changes since 1895. Source: Third National Climate Assessment, http://nca2014.globalchange.gov/report/our-changing-climate/observed-change#tab2-images

Scientific Consensus

The scientific understanding of the drivers of climate change is settled. The vast majority of climate scientists (between 90% and 100% of scientists) agree that climate change is being driven primarily by human activities (Myers et al. 2021). The scientific literature also demonstrates the validity of this conclusion – since 2012 over 99% of climate-related peer-reviewed publications (the standard for scientific research) have concluded that contemporary climate change is being driven by human activities (Lynas, Houlton, and Perry 2021).

Nearly all major U.S. scientific societies, including those representing physicists, astronomers, chemists, biologists, geologists, and meteorologists (https://climate.nasa.gov/scientific-consensus/); international scientific societies; and national academies of science also agree on the role of human activities as a primary driver of climate change (https://www.opr.ca.gov/facts/list-of-scientific-organizations.html).

Baseline Climate Data for the Quad Cities Region

To better understand the past and current climate of the Quad Cities area, we examined the instrumental weather and climate records from 1895 through the present. We used the Parameter-elevation Regression on Independent Slopes Model (PRISM) 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 regional variations in weather and climate that occur due to complex terrain, rain shadows, elevation, and ***aspect*** – all of which affect weather and climate across the Quad Cities region.

Temperature in Historical Perspective

Annual average temperature refers to the average of the highest and lowest temperatures each day averaged over a whole year. The lowest annual average temperature in the Quad Cities area was in 1913 at 51.4° F degrees. The highest annual average temperature was in 2017 at 57.4° F. Throughout this report, we will use the period 1961 – 1990 as a reference period, in alignment with the National Climate Assessment. For that period, the annual average temperature for the Quad Cities area was 53.9°F. Although year-to-year variability in temperature are natural and expected in this region (illustrated in Figure 7 by the many points above and below the long-term average orange line), we see a fairly consistent upward trend in annual average temperatures since the mid-1980s. In Figure 7, the straight horizontal line represents the reference period average (53.9° F), 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**.

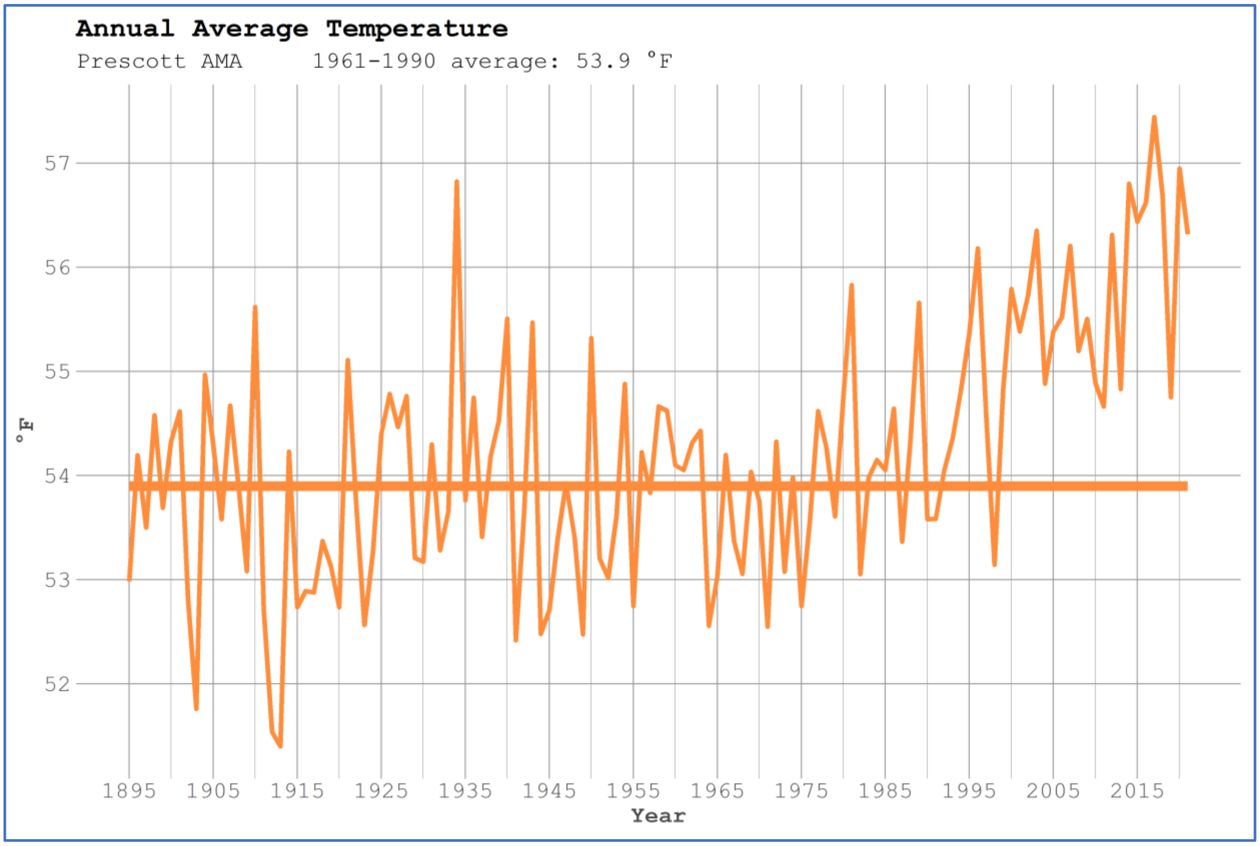

Figure 7: Annual average temperatures for the Prescott AMA 1895 – 2021. The annual average temperature for the 1961 – 1990 reference period was 53.9 °F. Almost every year since 1985 has seen average annual temperatures above this long-term average.

Disaggregating temperatures as average daily maximum, average daily minimum, as well as overall average allows us to identify patterns in how warming is impacting the 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 Quad Cities area have been rising faster than *maximums* (shown in red) – although both are rising. Minimum temperatures have been consistently above average and rising since the year 2000. 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 23).

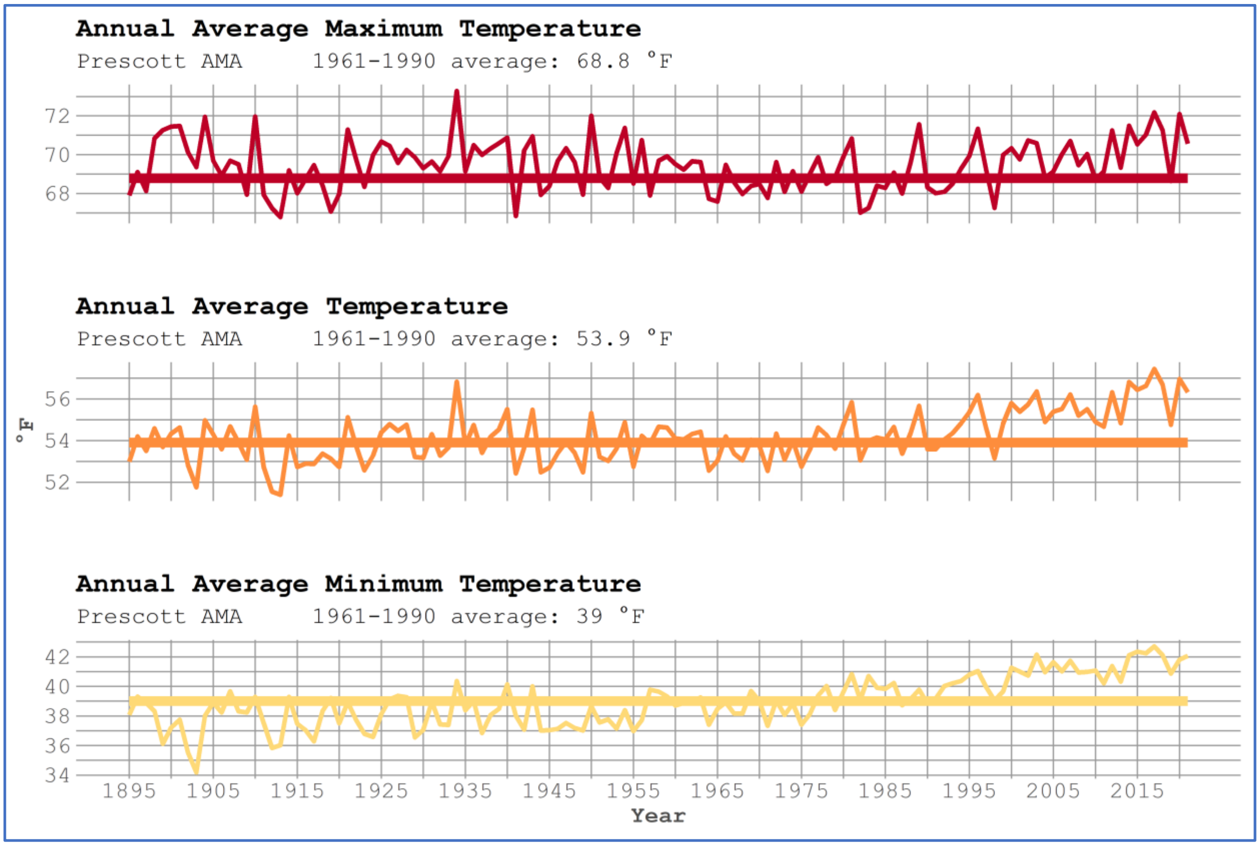

Figure 8: Annual average maximum (red), minimum (yellow), and overall average (orange) temperatures for the Prescott AMA from 1895 – 2021. Minimum temperatures are rising even faster than maximum temperatures; both are pushing the overall average temperatures higher.

Precipitation in Historical Perspective

As is normal in the southwestern U.S., precipitation across the Quad Cities area is highly variable and has ranged from a high of 39.3 inches in 1905 (1905 was a record precipitation year across the region) to a low of 7.3 inches in 1956. The average annual precipitation across the Quad Cities area between for the reference period 1961 – 1990 was 18.2 inches (Figure 9). In Figure 9, green bars represent years with above-average precipitation and brown bars represent years with below-average precipitation.

The Quad Cities area 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 to early 1960s, and throughout the 2000s so far. These drought periods were felt across a broad swath of the Southwest.

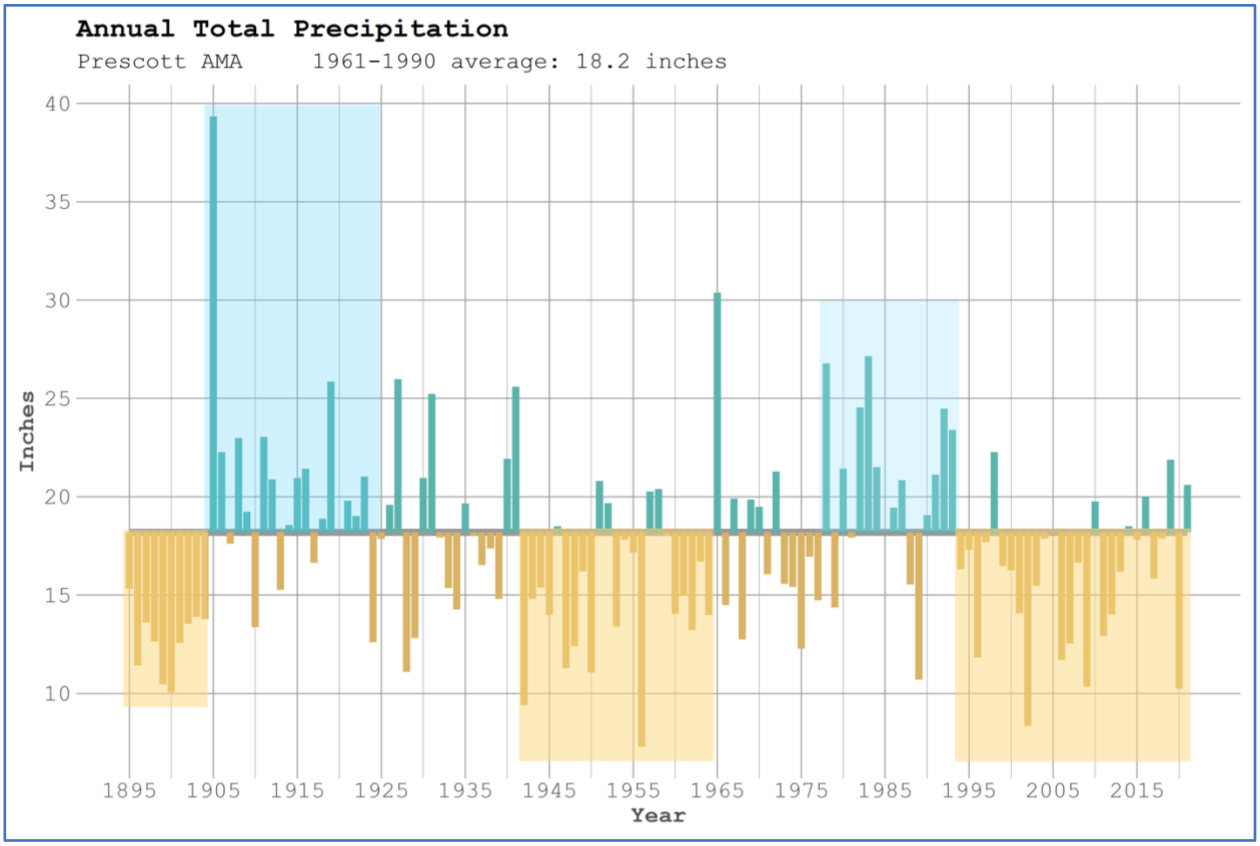

Figure 9: Average annual precipitation for the Prescott AMA 1895 – 2021. Annual average precipitation for the 1961 – 1990 reference period was 18.2 inches, but the region experiences naturally highly variable precipitation year-to-year.

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 climate models to estimate future global average temperatures and other climate variables.

Table 1 summarizes the assumptions and projections for the RCPs. 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 8.5 *red line and shading*	Higher Scenario - 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).
RCP 4.5 *aqua line*	Lower Scenario - 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 2.6 *green line and shading*	Even Lower Scenario - Assumes that 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).

Figure 10 shows the projected global temperature increases under the emissions scenarios described in Table 1. The black line in the left panel represents the observed change in GHG emissions since 1900. The red line in the left panel represents the higher emissions scenario for GHGs as described in Table 1. The aqua line in the left panel represents the lower emissions scenario and the green line represents the even lower emissions scenario. In the panel to the right, the black line represents the observed global average temperature since 1900. The colored lines (red, aqua, and green) represent the projected temperature increases associated with each of the emissions scenarios. The shading around each of the lines represents the spread of the projections from each of the individual 32 models; the solid lines are the averages of the outputs of all 32 models. Although there is a range of possible temperatures for each scenario (shaded areas), they all project rising temperatures. In this report, we use only the lower scenario (RCP 4.5) and higher scenario (RCP 8.5) because the even lower scenario is no longer attainable.

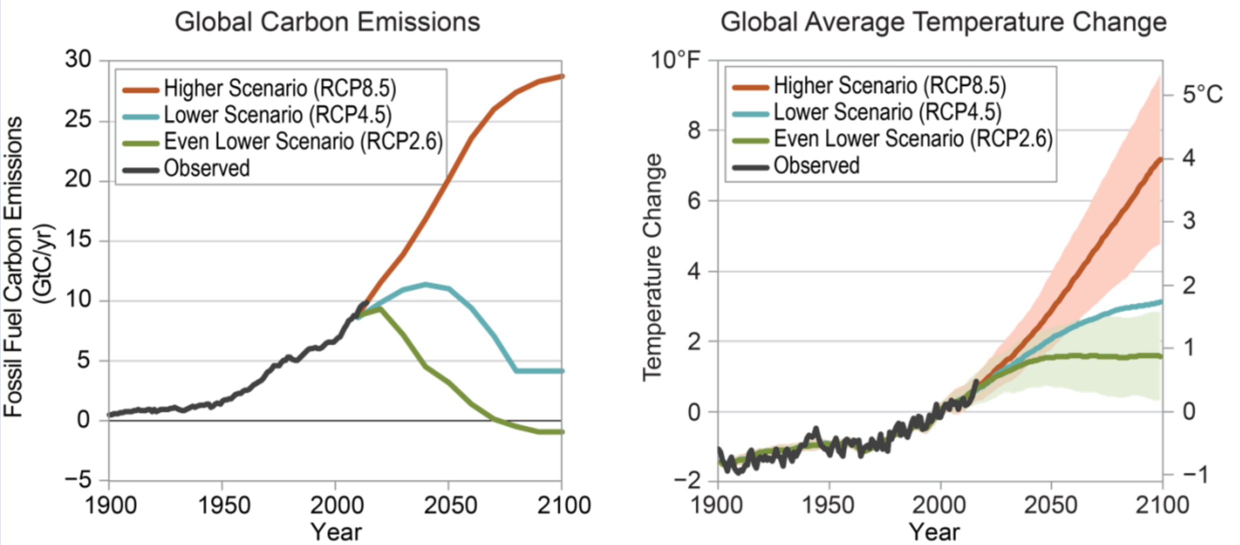

Figure 10: Observed and projected changes in global average temperature (right) depend on observed and projected emissions of carbon dioxide from fossil fuel combustion (left) and emissions of carbon dioxide and other heat-trapping gases from other human activities, including land use and land-use change.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

Using Scenarios in Decision Making

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. 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)

Regional Climate Models

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 Prescott AMA 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. This reference period aligns with one used for the most recent National Climate Assessment, so changes in the Quad Cities area can more easily be compared and contrasted with those occurring in other communities and other regions around the country. The Climate Explorer (https://crt-climate-explorer.nemac.org/) is a tool that allows for easy comparison of county-scale data.

Climate Projections for the Quad Cities Area

Annual Average Temperature

Model projections for the Quad Cities region show a range of possible future temperature increases, depending on the climate scenario. The average annual temperature for the reference period 1961 – 1990 was 54° F[2] (Figure 11). As described earlier, the solid lines in Figure 11 (and subsequent figures) represent the average of all the 32 model projections for each scenario while the shaded areas present the range of projections from all the models.

The annual average temperature is projected to climb 4 – 5 degrees F by 2050 for RCP 4.5 and 8.5, respectively, to approximately 58 - 59° F, which is the current average temperature of Albuquerque, NM. By the end of the century, annual average temperatures could be between 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. End of century annual average temperatures could be 65° F. For comparison, the annual average temperature in Tucson, AZ now is approximately 68° F.

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[2] There is a slight difference between the modeled historical temperature data and the observed record data. Figure 11 contains a modeled historical average of 54° F, while the observed record is 53.9° F. Slight differences in the modeled historical data do not affect the clear data about direction of change – temperatures are rising, despite small uncertainties about specific magnitudes.

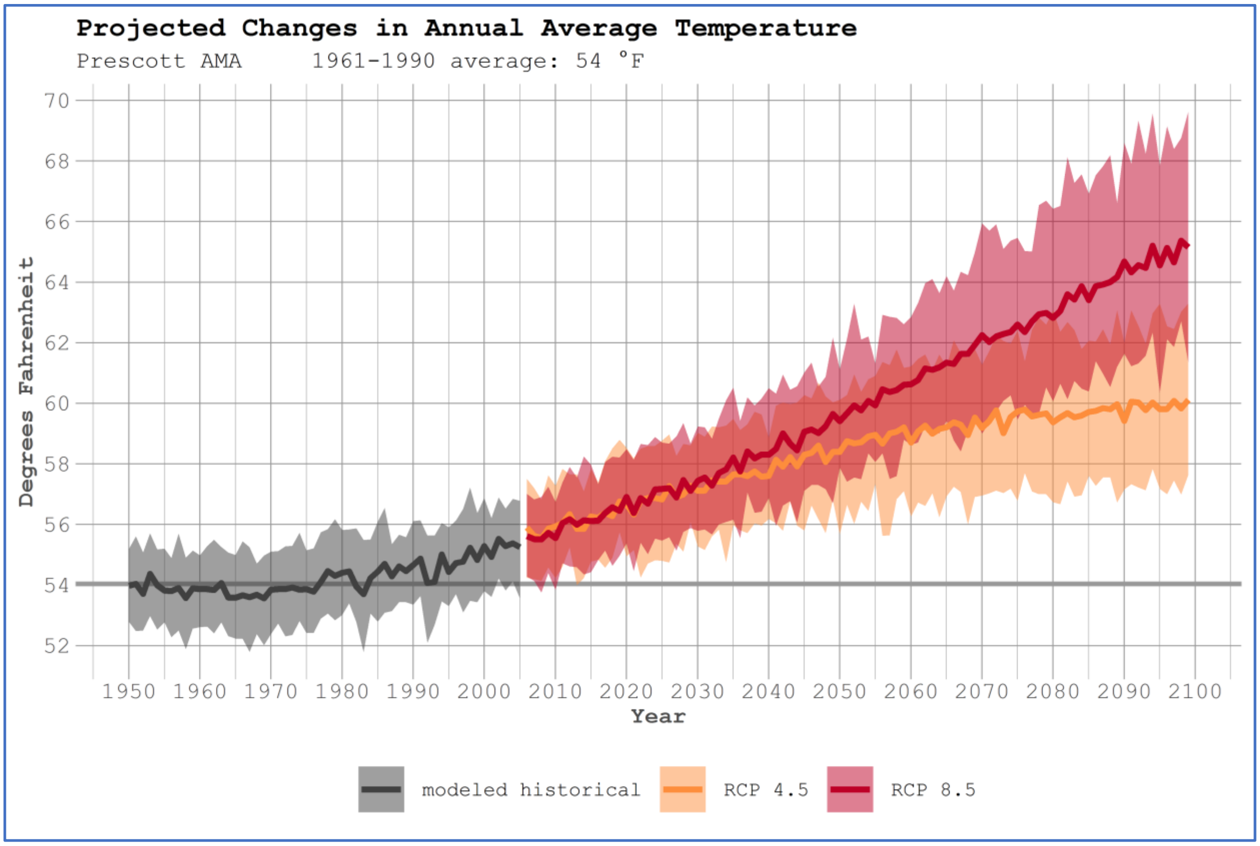

Figure 11: Downscaled model projections for the Quad Cities area show a range of possible future temperature increases, from 6° F higher than the 1961–1990 average for RCP 4.5 (orange line) to 11° F higher for RCP 8.5 (red line) at the end of this century.

Temperature Extremes

The average number of days above 95° F in the Quad Cities area has been 8 days per year (between 1961 and 1990) (Figure 12). **Recently, the area has seen about 20 days per year over 95. The projected change in the number of days above 95° F by 2100 ranges from 35 – 40 days by 2050 and 50 days per year (lower scenario) to as many as 95 days per year (higher scenario) by the end of the century.**

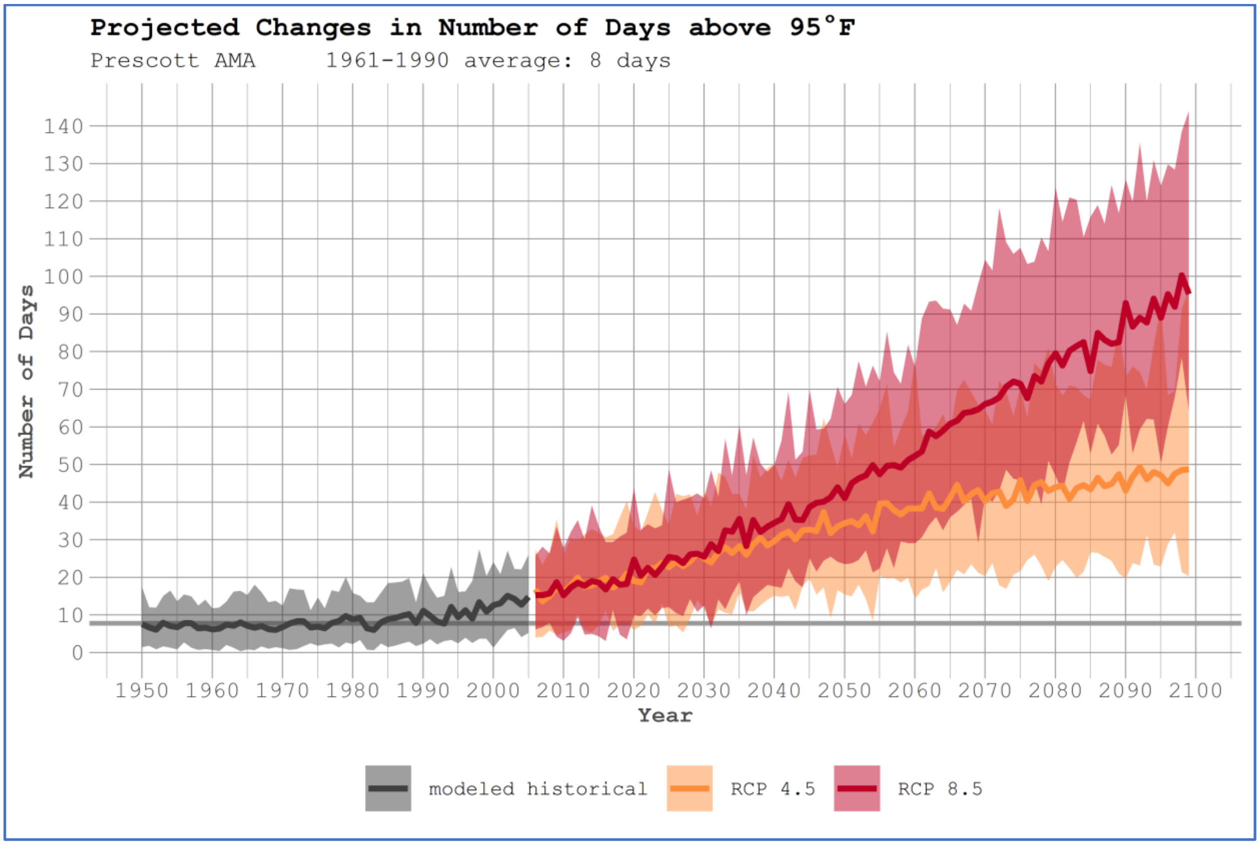

Figure 12:Projected changes in number of days with high temperatures reaching above 95 °F for the Quad Cities area. The area could experience between 50 and 95 days with maximum temperatures over 95 °F by the end of the century.

The Quad Cities area averaged about 1 day per year above 100° F between 1961 and 1990 (Figure 13). **More recently, the area has seen about 5 days per year over 100. The projected change in the number of days above 100° F range from: 10 – 12 days by 2050 and 15 days per year (lower scenario) to as many as 55 days per year (higher scenario) by the end of the century.**

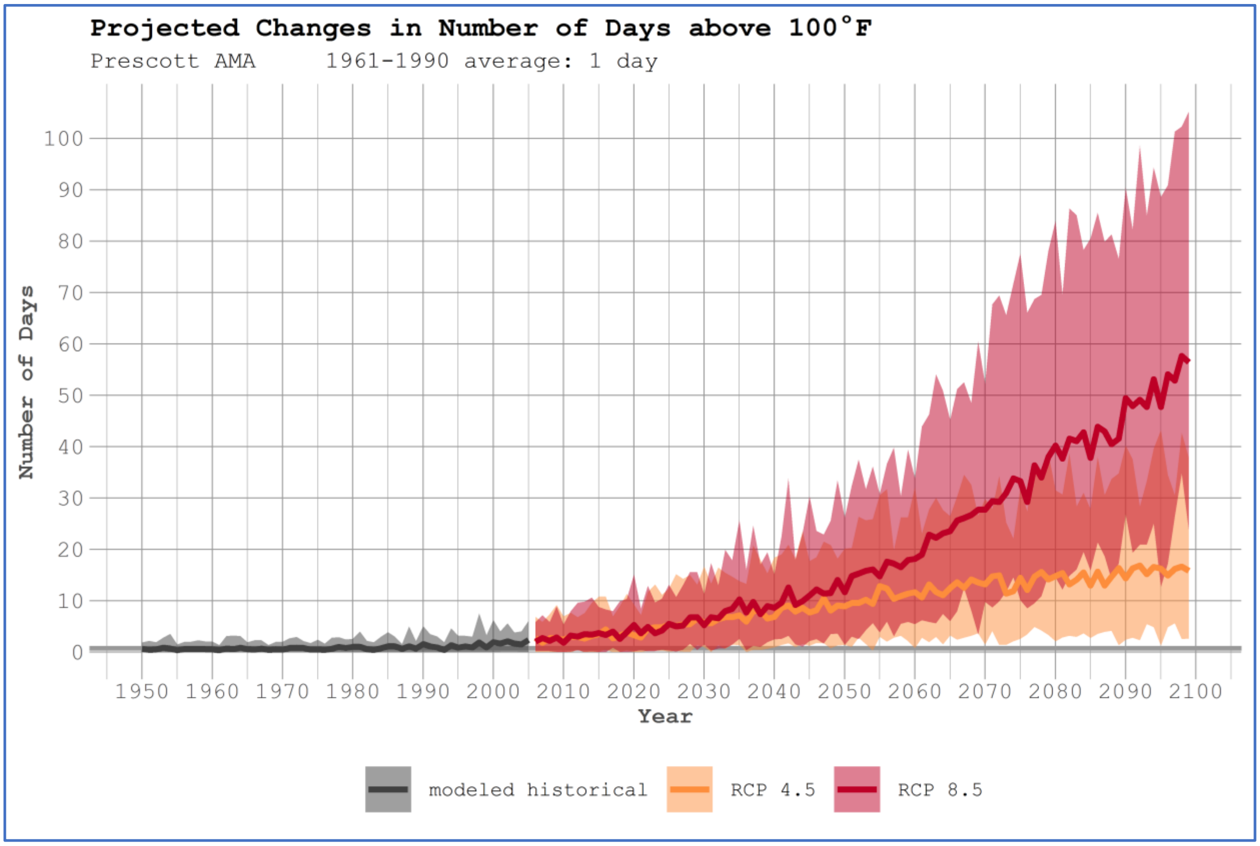

Figure 13: Projected changes in number of days with high temperatures reaching above 100 °F for the Quad Cities area. The area could experience between 15 and 55 days with high temperatures over 100 °F by the end of the century.

On average, the Quad Cities area has experienced 133 days per year in which the minimum temperature is 32° F or colder (1961 – 1990) (Figure 14). **Projections for the region indicate that the number of days with temperatures that fall below the freezing point could decrease to between 95 and 100 days by 2050 and to 90 days per year (lower scenario) and as few as 55 days (higher scenario) by the end of the century.**

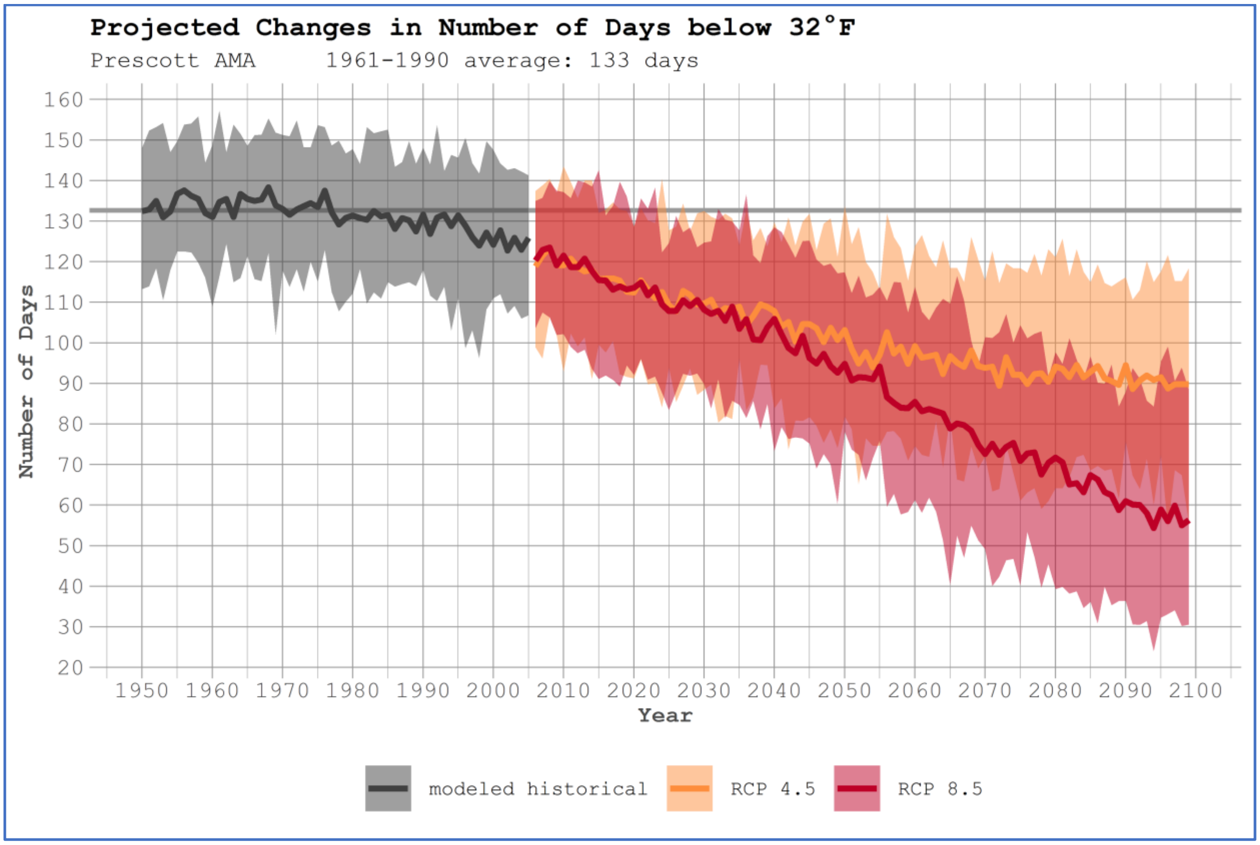

Figure 14: Projected changes in number of days with low temperatures falling below 32 °F for the Quad Cities area. The area could experience as few as 55 days with low temperatures below 32 °F by the end of the century.

Growing Season

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 Quad Cities region was about 167 days per year between 1961 and 1990. Based on the projected temperature changes for the Quad Cities, **the growing season is likely to increase by between about 30 days (lower scenario) and 60 days (higher scenario) by the end of the century** (Figure 15).

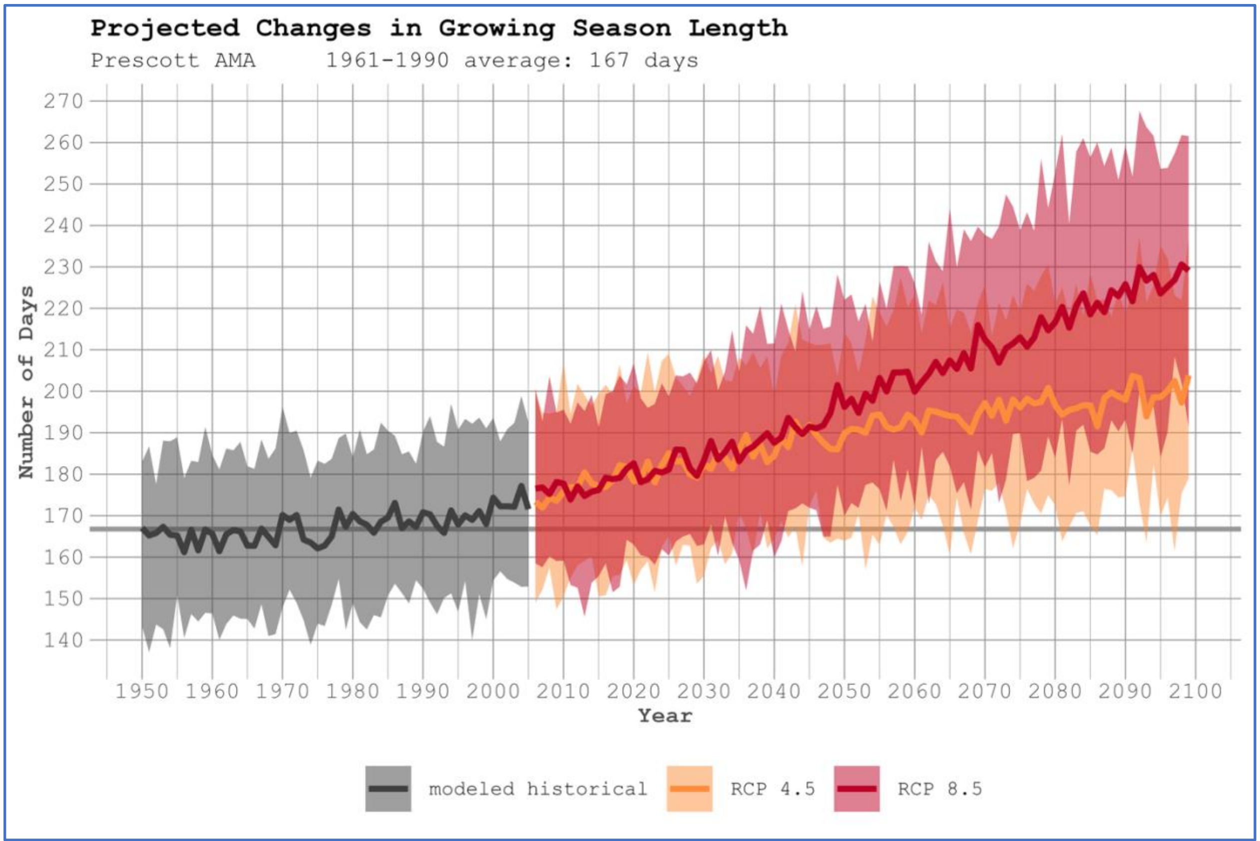

Figure 15: Projected changes in the growing season length for the Quad Cities area. Between 1961 and 1990 the growing season was 167 days on average. The growing season is likely to increase by between about 30 days and 60 days by the end of the century.

Annual Average Precipitation

While the projections for *temperature* show possible increases in both scenarios, **the projections of annual total precipitation show little-to-no change for the Quad Cities area** (Figure 16). 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.

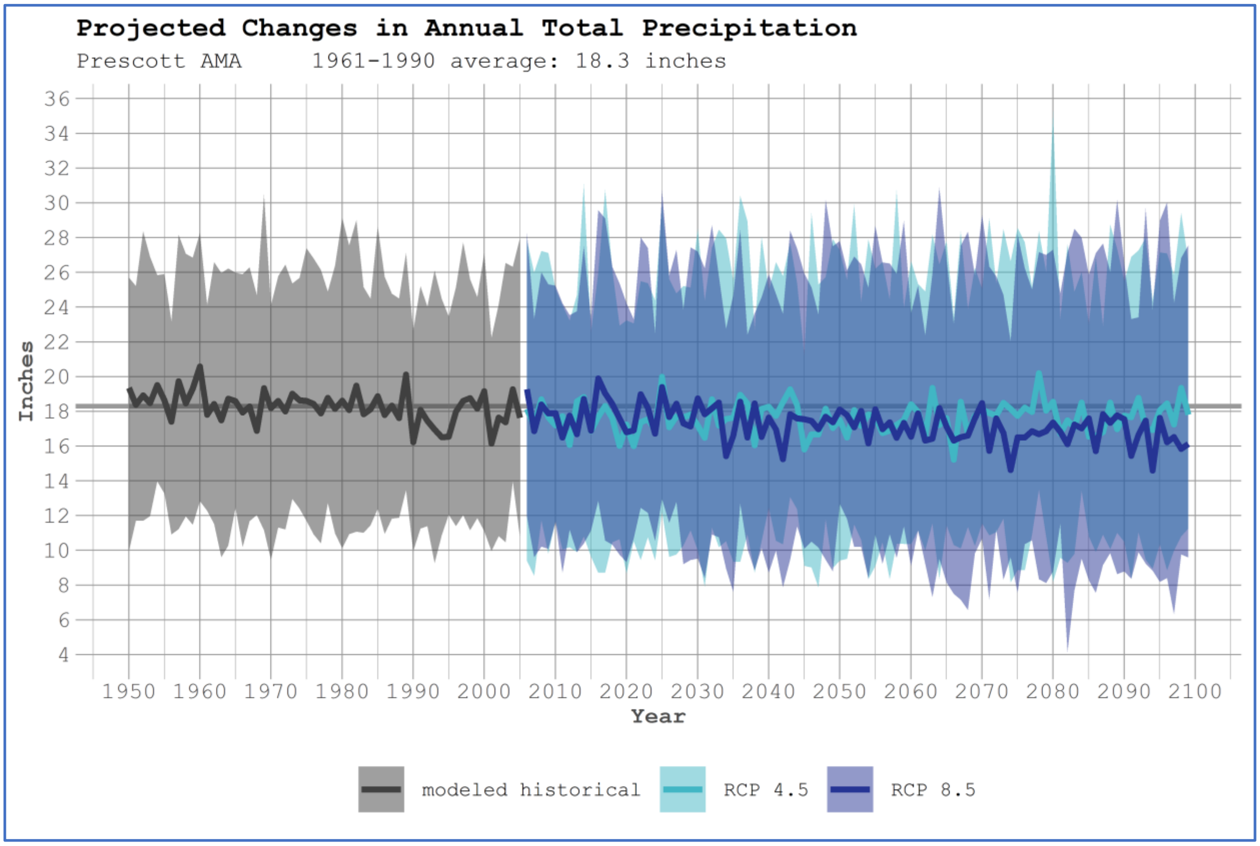

Figure 16: Between 1961 and 1990 the annual average precipitation for the Quad Cities area was 18.3 inches. Projections of future precipitation show little change and are more uncertain than projections of temperature changes,

Precipitation Extremes

While scientists are very certain about the projections of future temperature change (i.e. warming), creating high-confidence projections of precipitation for this region has proven very difficult. Multiple phenomena influence this region's precipitation, including the ***El Niño Southern Oscillation (ENSO)***, the ***Pacific Decadal Oscillation (PDO)***, the ***North American Monsoon (NAM)***, and ***atmospheric rivers*** (Sheppard et al. 2002; Crimmins et al. 2017). Each of these phenomena play out on the landscape in different ways that contribute to precipitation (or lack thereof); the diversity of phenomena is difficult to capture in a climate model. Therefore, 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)[3].

Changes in Character of Precipitation

Although projections of changes in precipitation amounts are uncertain, based on our understanding of the physical effects of climate change, we can describe likely changes to the *character* of precipitation in this region. As the atmosphere warms, it will be able to hold more moisture, which will produce more extreme precipitation when that precipitation falls. According to analyses included in the Fourth National Climate Assessment (Figure 17), **northern Arizona could see up to 20% more of its precipitation falling in the very heaviest (i.e. top 1% heaviest) events by the end of this century** (Jay et al. 2018).

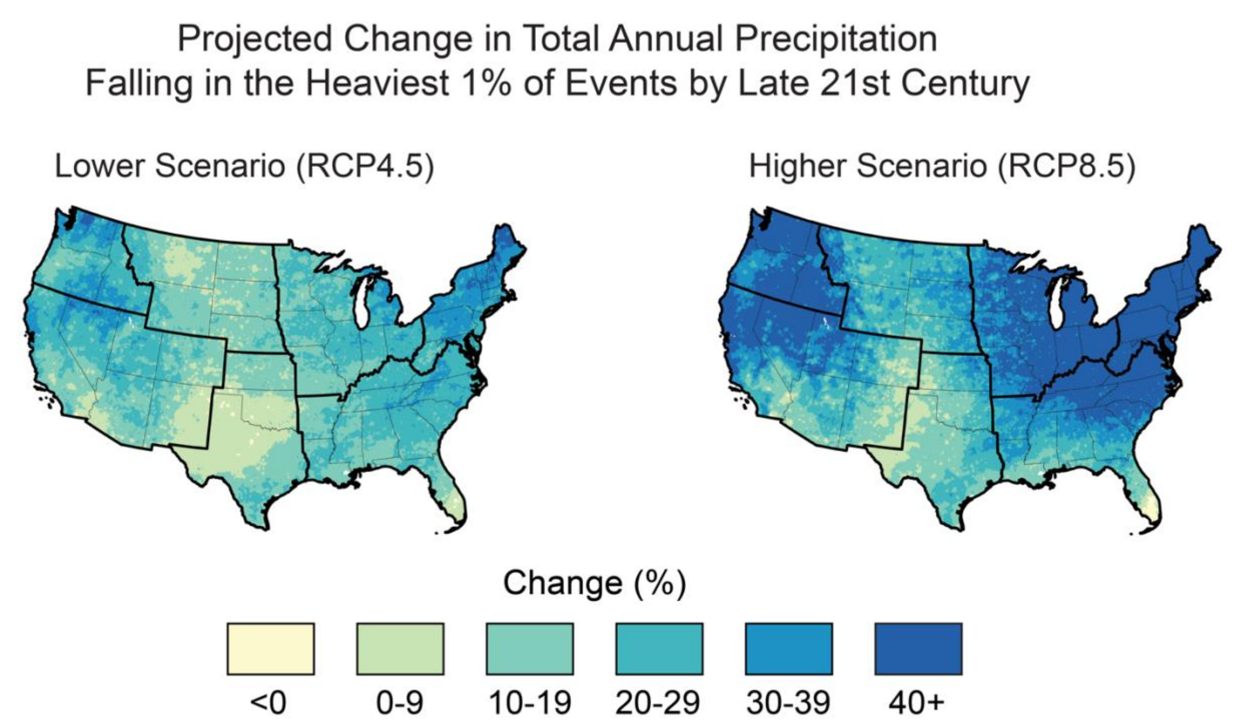

Figure 17: Source: https://nca2018.globalchange.gov/chapter/2#section-kf-key-message-6.

We can see how the warming atmosphere is likely to change storm events in the future by looking at the projected changes in daily maximum precipitation. Annual daily maximum precipitation is a measure of the largest, single day precipitation event that falls each year. Between 1961 and 1990, the average of daily maximum precipitation (average of all the daily

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[3] 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).

maximums) was 2.7 inches. In Figure 18 we do not see much projected change according to the model average lines – they both show the possibility of the average daily maximum precipitation reaching about 3 inches. However, when we look at the shaded area, which reflects the range of the data from each of the 32 models used in this analysis, we see that the shaded area is larger above the average line. This indicates that there is a **greater likelihood of larger storms with higher daily maximum precipitation in the future**.

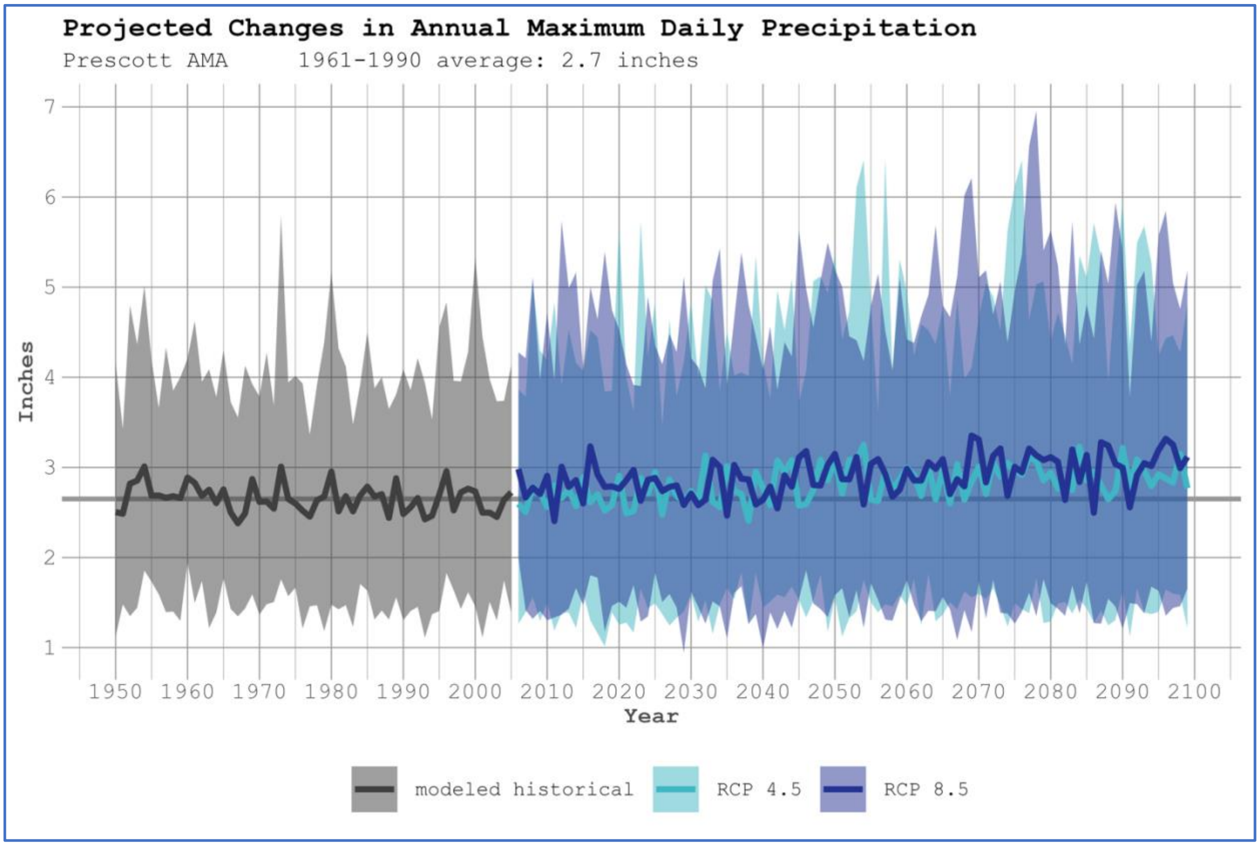

Figure 18: Between 1961 and 1990, the average of daily maximum precipitation in the Quad Cities area was 2.7 inches. There is little projected change according to the model average lines. However, the shaded area is larger above the average lines, which indicates that there is a greater likelihood of larger storms with higher daily maximum precipitation in the future.

Recent research on the ***North American Monsoon*** (NAM) and ***atmospheric rivers*** (ARs) points to changes that may affect the Quad Cities. In addition to allowing the atmosphere to hold more moisture, warmer temperatures are related to expansion and intensification of the monsoon ridge. The monsoon ridge, which is a ridge of high pressure that acts to block moisture flow toward the north, determines where storms develop and move. These changes in the monsoon ridge result in fewer storms across Arizona during the peak of the monsoon season (late-July to mid-August) (Lahmers et al. 2016). **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).** 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). As storms, like those associated with the NAM, have become more extreme in terms of precipitation, maximum wind gusts also have become higher. Higher winds during severe storms are also projected to continue in the future (Luong et al. 2017; Castro 2017). **While the overall average amount of precipitation may not change substantially, the Quad Cities may receive that precipitation in fewer, but more intense storms** (Castro 2017).

Another mechanism for extreme precipitation is atmospheric rivers (ARs), narrow corridors of concentrated moisture in the atmosphere that create extreme precipitation events in the western U.S. 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 but also providing additional opportunities for aquifer recharge. However, the dynamics of these types of storms, which tend to be strongly affected by the topography of a region (precipitation is more likely to occur in mountainous areas), means that the actual impacts will be highly variable and difficult to predict at local to regional scales.

While storms may become more extreme, the region may experience fewer of them. Projections suggest an increase in the number of dry days, or days with less than .1 inches of rain. The Quad Cities had an average of 265 dry days per year during the 1961 – 1990 reference period (Figure 19). However, **by 2050, the area could have an additional 10 days without precipitation (both the lower and higher scenarios). By the end of the century, dry days are projected to be approximately 275days per year (lower scenario) to 285 days per year (higher scenario)**.

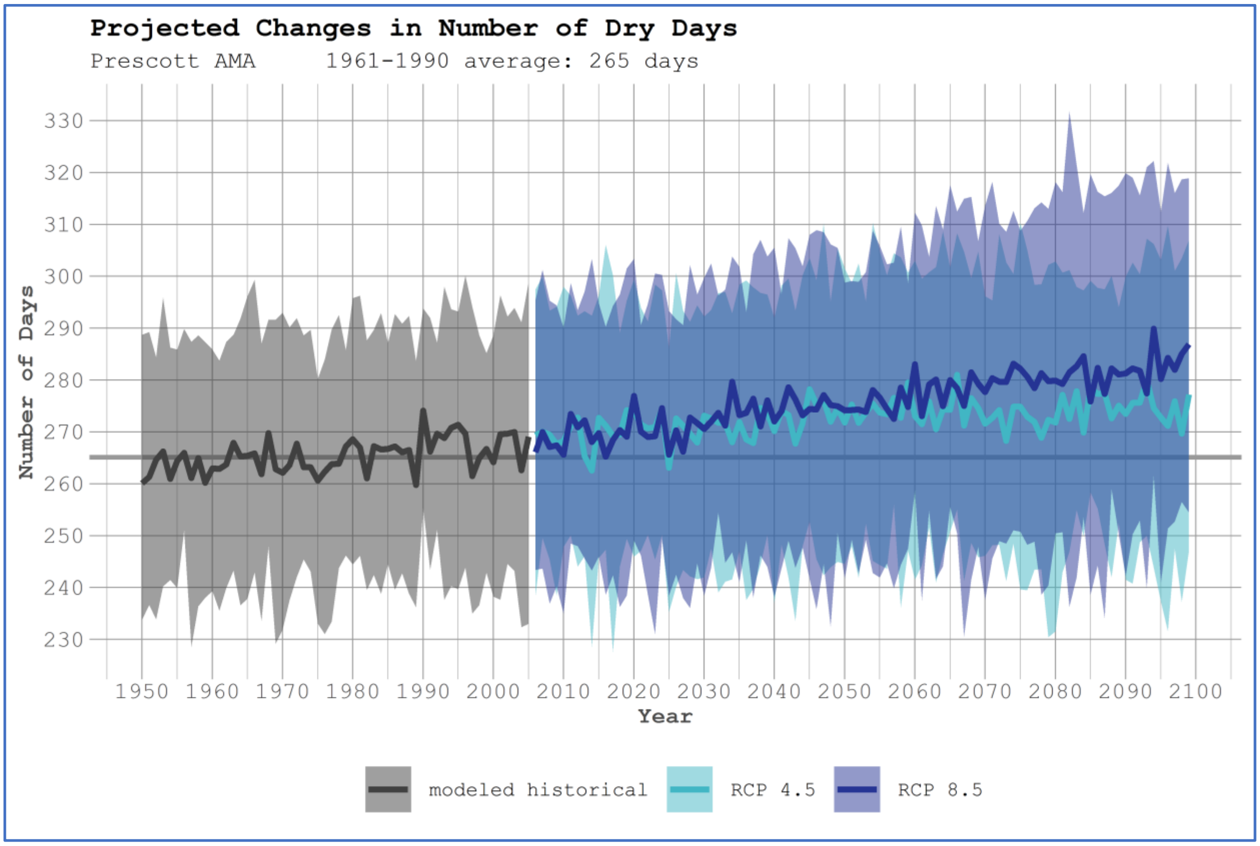

Figure 19: The Quad Cities averaged 265 dry days (less than .1 inches of precipitation) between 1961 and 1990. Projections for the area indicate a rise in dry days to between 275 and 285 days per year by the end of the century.

Even if with no change in total precipitation, the Quad Cities 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 (See Drought on page 41).

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 Quad Cities' specific climate projections into a regional context. This section does not provide impacts analyses specific to the Quad Cities.

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, Comrie, and Drechsler 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 the higher emissions 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 those projected for 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.

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, Comrie, and Drechsler 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 20). However, ozone in Yavapai County tends to peak in the hotter months preceding the monsoon season – April through June (Figure 21). As temperatures rise and heat waves become more common, ozone exceedance days may also rise.

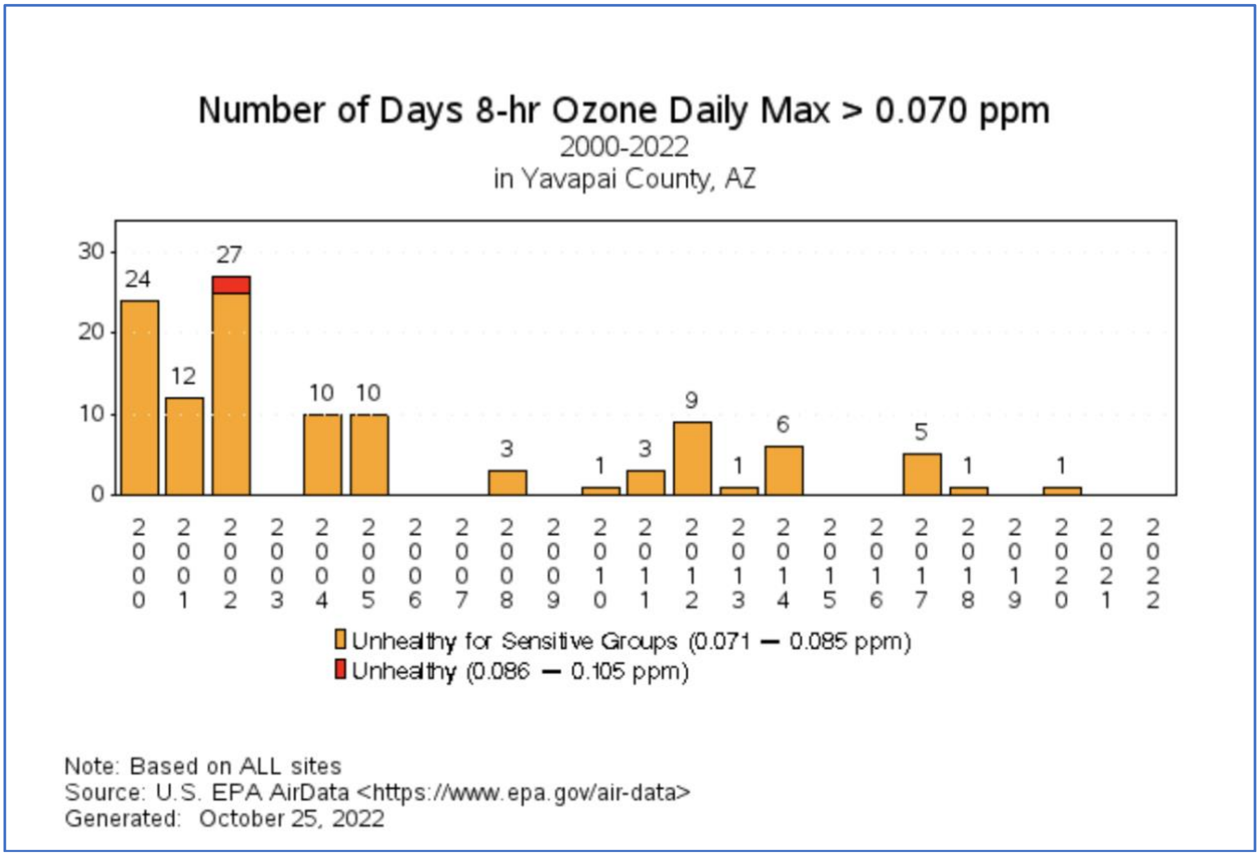

Figure 20: Number of days ozone levels have exceeded 0.07 parts per million (ppm), which is unhealthy for sensitive groups, and 0.086 ppm, which is unhealthy for all. Source: https://www.epa.gov/outdoor-air-quality-data/air-data-ozone-exceedances.

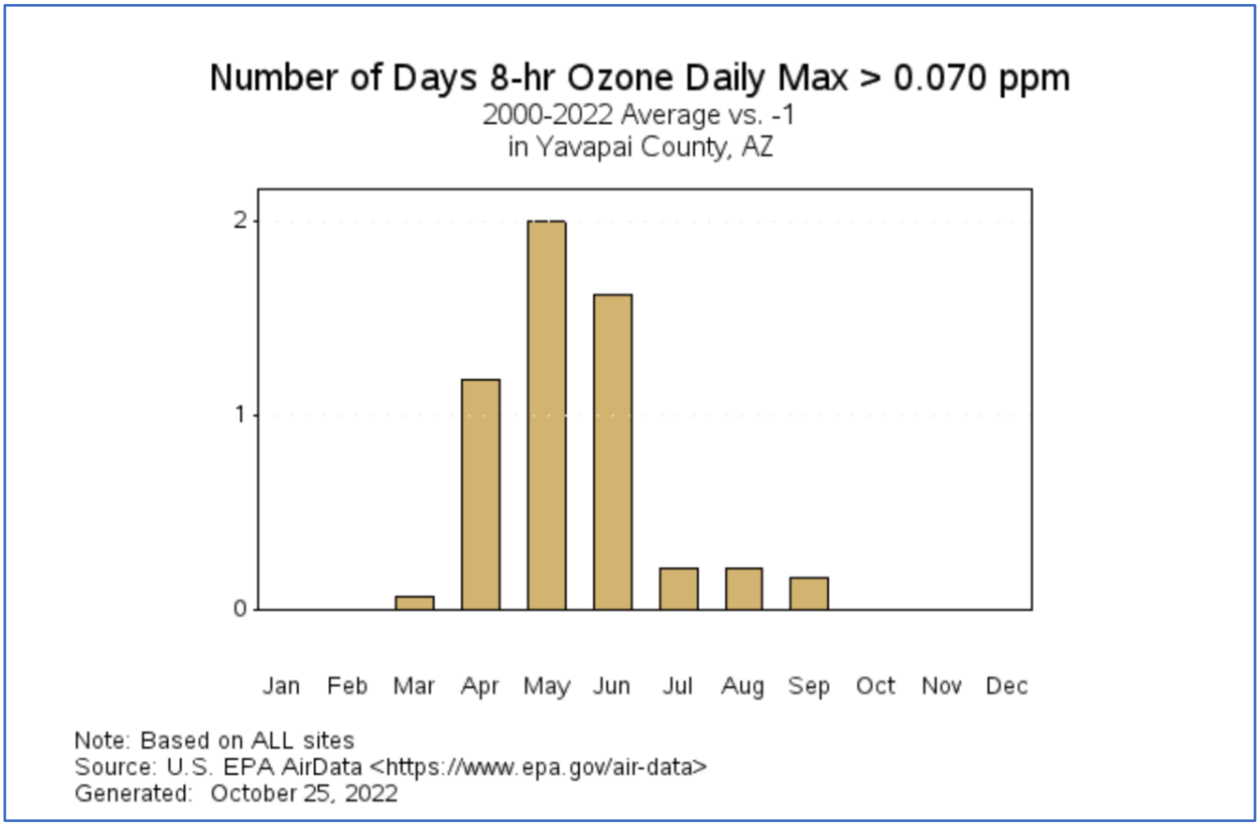

Figure 21: Average number of days from 2000 to 2022 in which ozone exceeded 0.070 ppm in each month. April - June, three of the warmest months, also had the highest number of high ozone days. Source: https://www.epa.gov/outdoor-air-quality-data/air-data-ozone-exceedances.

PM2.5 is often generated by vehicle exhaust and power plant emissions (Environmental Protection Agency 2013). Another source of PM2.5 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 39). A recent nationwide analysis found that wildfires have accounted for up to 25% of PM2.5 in recent years and up to 50% in some Western regions (Burke et al. 2021). High levels of PM2.5 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). The increase of days with smoke in the air, due to wildfires, threatens to undo the improvements the country has seen in air quality in recent decades (Burke et al. 2021).

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 22) (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 23) (Tong et al. 2017). Dust can enter the nose and lungs and create serious health problems.

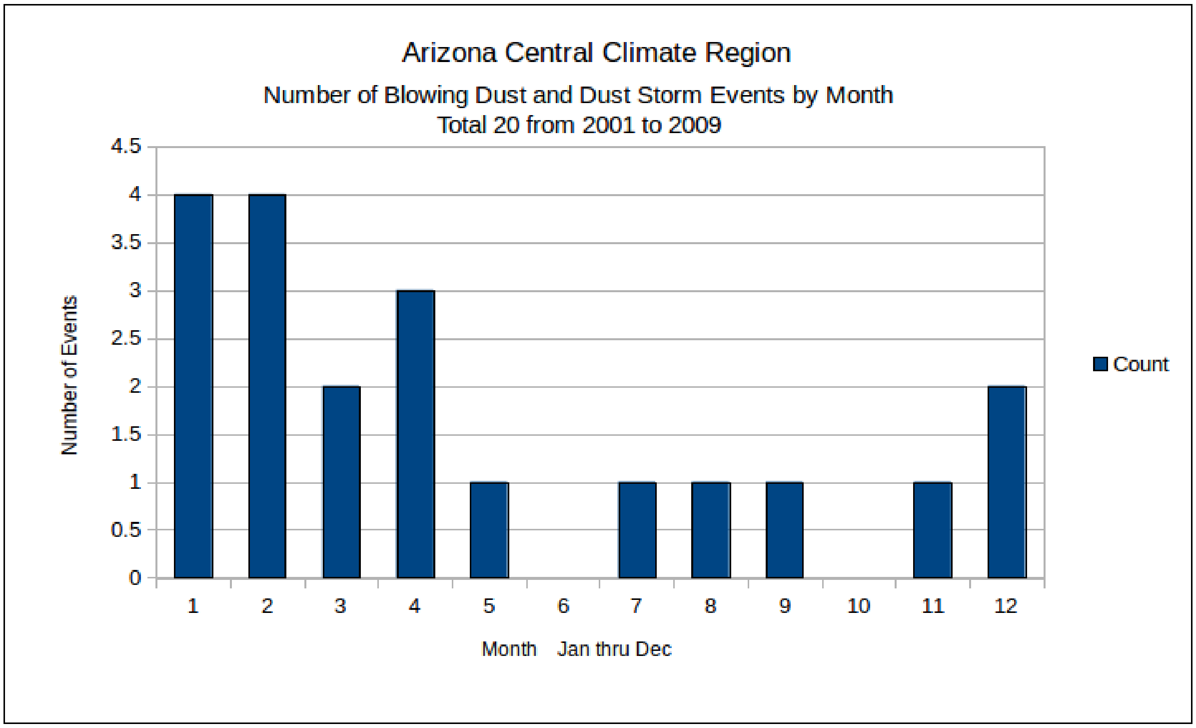

Figure 22: Monthly frequency of blowing dust and dust storms in the Central climate region, including most of Yavapai and Gila Counties, from 2001-2009. Most events occurred in December – April. Source: Lader et al. (2016).

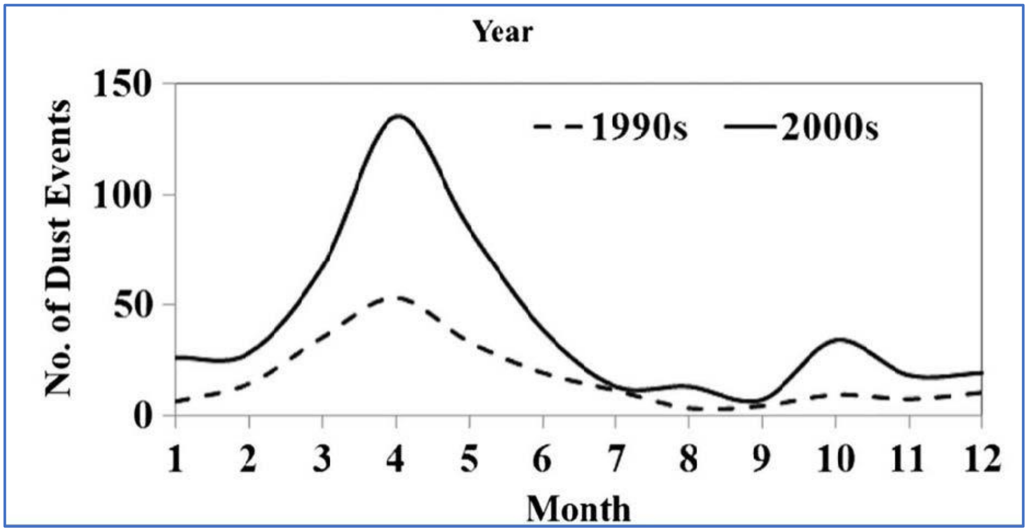

Figure 23: Monthly distribution of dust events across the western United States in the 1990s and 2000s. Source: Tong et al. (2017). The dashed line represents the total number of dust events in the decade of the 1990s; the solid line represents the total number of events in the decade of the 2000s. The 2000s had more dust events in almost every month than in the 1990s.

Vector-borne and Climate-related 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 primary mosquitos that carry WNV in the region are *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).

Although not currently a common occurrence in the Quad Cities area, Valley fever may pose additional risks in the future due to climate-related changes. Valley fever (VF) is a fungal disease that is at least partially influenced by climate and weather conditions. Predicting changes in VF cases 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. The timing of these weather 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 ability to detect fungus in the soils remains limited, it is difficult to predict if and when VF 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

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 (Bentz et al. 2022), the *Ips* bark beetles are of greater concern in the forests surrounding the Prescott Basin (Negron et al. 2009); Arizona five-spined *Ips* and pine engraver beetles (also in the *Ips* genus) are the primary mortality agents of ponderosa pine and pinyon *ips* in piñon pine. Warmer and drier climate in combination with suitable forest conditions contribute to increased potential for current and future bark beetle outbreaks (Bentz and Logan 2009; Negron et al. 2009). Warming temperatures will likely lengthen the period of flight activity and increase the number of generations per year for *Ips* species (Williams et al. 2008).

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 24) (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 and Williams 2016).

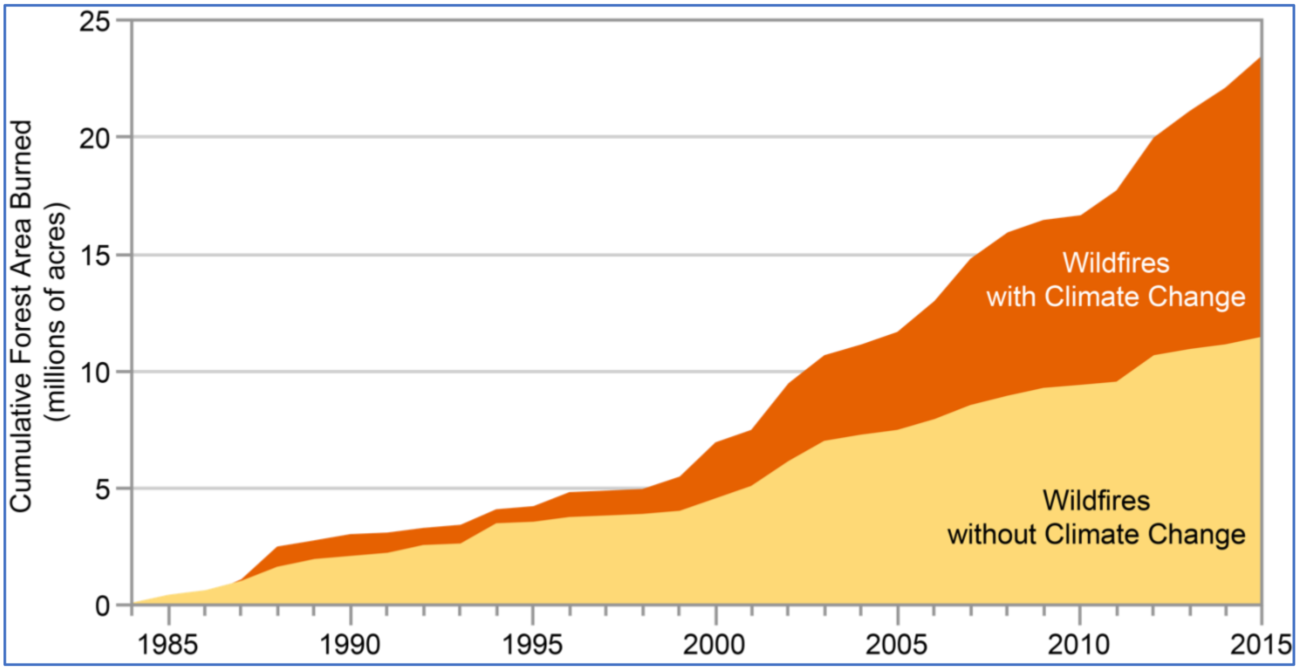

Figure 24: The cumulative forest area burned by wildfires has greatly increased between 1984 and 2015, with analyses estimating that the area burned by wildfire across the western United States over that period was twice what would have burned had climate change not occurred. Source: Figure 25.4 from 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). Under the higher emissions scenario, 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.

Communities in the wildland-urban interface (WUI) are at particular risk from increased fire frequency and size. Both people and infrastructure will be increasingly vulnerable without appropriate adaptation strategies (USDA Forest Service 2022; U. S. Department of Agriculture 2021). The number of homes in the WUI is also contributing to the cost of fighting wildfires because firefighting effort focuses heavily on protection of private homes. Nationwide, there are approximately 49 million residential homes in the WUI and that number grows by about 1 million every three years (Burke et al. 2021). 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). According to analysis done by the Federal Emergency Management Agency, Yavapai County has a slightly greater overall risk score than Arizona as a whole – with wildfire posing the greatest risk within the county (https://hazards.fema.gov/nri/report/viewer?dataLOD=Counties&dataIDs=C04025)

Flooding

Although overall precipitation may remain steady, individual precipitation events may become more extreme because a warmer atmosphere holds more water (see section on Changes in Character of Precipitation on page 29). Areas in and around the Quad Cities 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. The FEMA National Risk Index (link above) places Yavapai County at relatively high risk for riverine flooding at present.

Post-fire Flooding

The combination of more frequent, larger forest fires and more extreme precipitation can lead to more post-fire flood events (Garfin et al. 2016). However, post-fire debris flows can occur even with relatively “normal” storms (Garfin et al. 2016). Post-fire floods can be dangerous and hard to predict. The effects of wildfires within fire footprints can linger for up to a decade. There are increased risks of debris flows for up to 3 to 5 years following fire as the ground cover and fine roots recover, and the risk of flash floods lingers for up to 5 to 8 years following fire as the soil returns to normal absorbance and vegetation regrows (Touma et al. 2022).

Post-fire floods can pose a direct risk to buildings, infrastructure, or people in their path. Post-fire floods can also decrease water quality by pushing sediment into water sources. 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 onto 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 of water by plants. Both streamflow levels and soil moisture levels (both of which can be used as drought indicators) are likely to be impacted.

According to analyses done as part of the Fourth National Climate Assessment (Figure 25), the Southwest will experience reductions in soil moisture of between 1 and 3mm by the end of the century (using the higher scenario). The loss of soil moisture will be particularly noticeable in the winter and spring, because of the reduction of snowpack – the region will lose the process of slow seeping of moisture into soil as snow melts.

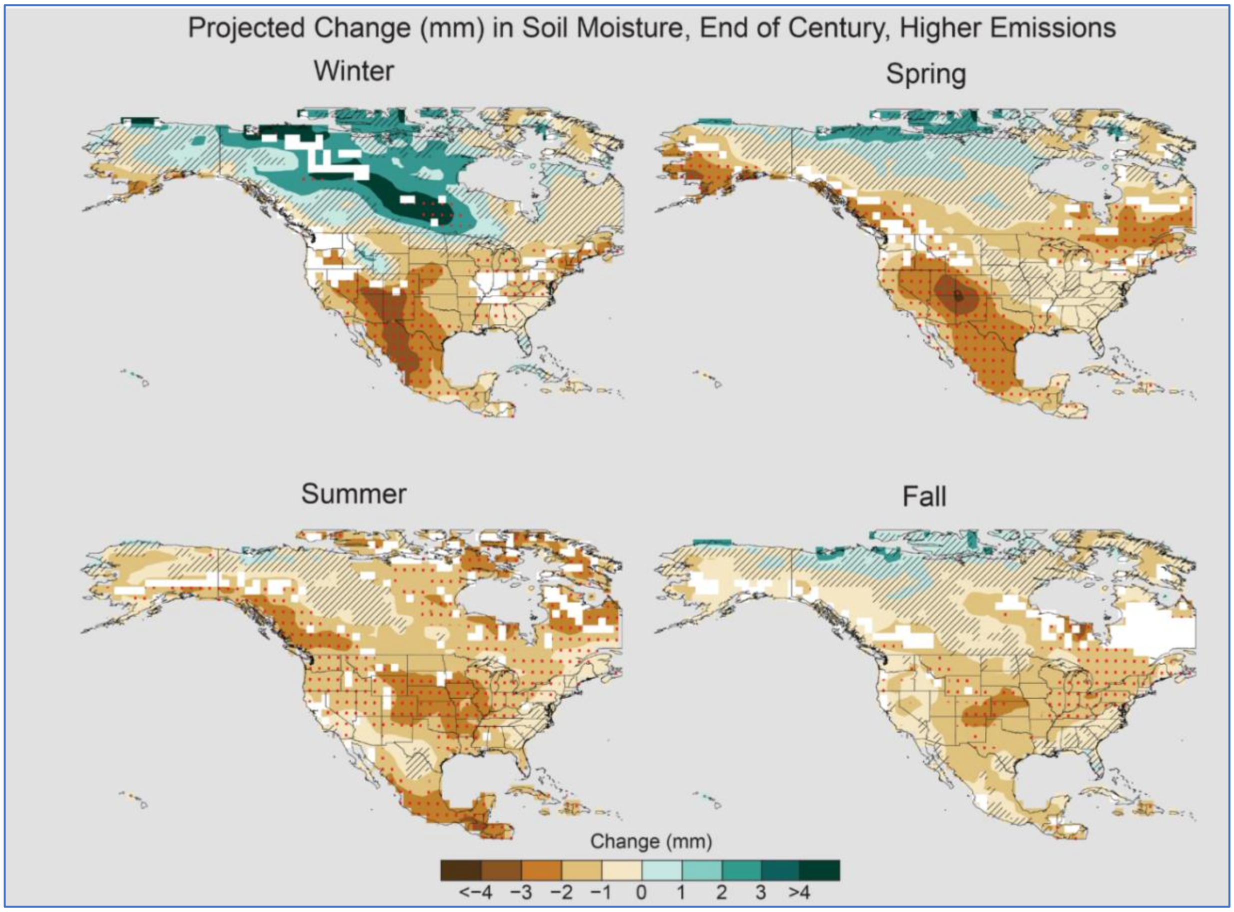

Figure 25: Projected changes in soil moisture by 2100 using the high emissions scenario. Source: https://science2017.globalchange.gov/chapter/8/

Another 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, 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 both the lower and higher emissions scenarios (RCPs 4.5 and 8.5) (Ault et al. 2014).

Water Resources

The Colorado River is the primary source of water for much of Arizona. Arizona and the states in the Lower Basin of the Colorado River are in a shortage declaration[4] as of January 2022, due to falling water levels in Lake Mead. While the Colorado River and Central Arizona Project (CAP) shortages will have wide-ranging implications for the state, the Prescott AMA does not receive water from the CAP.

The Prescott AMA relies exclusively on groundwater to meet its municipal, residential, and agricultural needs, which means that the communities depend on aquifers continuing to recharge through precipitation events in order to maintain consistent water resources for the area. Under the 1980 Arizona Groundwater Management Act, the management goal for the Prescott AMA is safe yield (a long-term balance between aquifer recharge and withdrawal) by 2025. However, according to the Arizona Department of Water Resources (ADWR), current groundwater pumping exceeds recharge at times by more than 20,000 acre feet per year (https://new.azwater.gov/ama/ama-data).

Indications for the Western US are that aquifer recharge rates are falling due to warming temperatures and changes in the character and patterns of precipitation (as discussed on page 29). According to climate projections for both the lower and higher emissions scenarios (RCP4.5 and RCP8.5), future changes in climate would reduce aquifer recharge in the southern part of the western US by 10%–20% (Meixner et al. 2016; Eastoe and Towne 2018; Georgakakos et al. 2014; Gonzalez et al. 2018). A recent study by the US Geological Survey (USGS) (Kennedy, Kahler, and Read 2019) of the Big Chino Subbasin, which lies just beyond the boundaries of the Prescott AMA, provides an example of this trend in the Quad Cities region. The USGS observed a small decrease in groundwater storage during the study period (2010 – 2017). The study also noted that no local recharge events from sustained rainfall occurred during the study period. Finally, the study found that baseflow discharge at the Verde River (which is fed by the subbasin) was consistently below the long-term average during the study period.

Verde River

Another way to understand the potential climate change impacts in the general region of the Quad Cities is to examine streamflow in the Verde River basin. Over the last 70 years, the Verde River basin has experienced significant increases in temperature, which are particularly evident in annual temperatures, and in early spring and summer (Woodhouse and Udall 2022). While few trends in annual or monthly precipitation are evident, trends in annual and monthly streamflow indicate decreasing flow over most months, and most strongly in April, May, and June.

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[4] For more information about the shortage declaration and the Central Arizona Project, please see: https://www.cap-az.com/water/water-supply/adapting-to-shortage/colorado-river-shortage/

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). A study simulating streamflow responses to projected climate change scenarios in the Verde River Basin found that stream drying events are projected to be longer and more frequent across the entire basin (Jaeger, Olden, and Pelland 2014). 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).

Water Quality

There are three main impacts to water quality from the rising temperatures and changes in precipitation patterns that are projected for the Quad Cities region: 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 and increase the risk of runoff from flooding (USDA Forest Service 2022). 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 other surface water levels, can increase the concentrations of nutrients in surface water, such as ammonia and nitrate, potentially raising the likelihood of harmful algal blooms and low oxygen conditions (Georgakakos et al. 2014).

With higher temperatures and changes in the character of precipitation including more extreme storms and more precipitation falling as rain instead of snow, the amounts of pollutants that wash from the ground and paved surfaces into streams and reservoirs increases (Georgakakos et al. 2014; USDA Forest Service 2022). Flooding and increased runoff from urban areas can carry pollutants such as oil, grease, and other automotive chemicals; pesticides and nutrients from lawns; bacteria from pet waste and septic systems (US Environmental Protection Agency 2021).

There is no one single factor affecting water availability and quality in the Quad Cities region. Population growth, water demand and use, changing climate, and water rights will all need to be considered by regional decision makers.

Agriculture

While farming and ranching are important to the character and heritage of several Quad City communities - particularly Chino Valley - most of the agricultural activity in the area consists of cattle ranching. In Yavapai County about 1% of land use is classified as agricultural[5]; of that, almost all (96%) is pastureland (U.S. Department of Agriculture 2017).

As is true in other agricultural ecosystems, rangelands are vulnerable to a number of climate impacts. The USDA notes that reduction in agricultural productivity is an overall risk to the sector (U. S. Department of Agriculture 2021), and both forage and livestock productivity are at risk due to reduced water availability, animal heat stress, and the increased spread of pathogens and parasites.

Rising temperatures are likely to result in a longer growing season (Figure 15), but with no increase in precipitation forage quantity and quality is likely to suffer. In turn, declining rangeland conditions may 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). Climate-driven changes in species composition (e.g. invasive species) and increasing wildfire frequency also pose a threat to rangelands in Arizona (Holechek et al. 2020).

For those agricultural producers growing crops and vegetables, The USDA notes that reduction in agricultural productivity is an overall risk to the sector (U. S. Department of Agriculture 2021). Crop yields are at risk of declining due to rising temperatures, reduced water availability, and increases in pests and disease persistence. Extreme high temperatures can cause heat stress to plants. They also can alter plant phenology by slowing or even stopping photosynthesis (Morales-Castilla et al. 2020). The generally rising temperatures are already contributing to changes in growing seasons, which can affect planting and harvest timing (U. S. Department of Agriculture 2021).

The increased warmth may increase pest persistence and allow new pests to become established in the region (Frisvold et al. 2013). While some agricultural pests are increasing, rising temperatures are impacting beneficial insects like pollinators, with implications particularly for specialty crops (U. S. Department of Agriculture 2021).

In addition to climate stressors on agriculture, communities in the Quad Cities may also face development pressures. As lands currently used for agriculture are converted to commercial and residential development, there may be greater stress on water resources and less land available for agriculture.

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

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 26: 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 (https://www.georgetownclimate.org/adaptation/plans.html).

Climate Adaptation Strategies

In this section, we present suggestions for possible climate adaptation strategies for the Quad Cities region. We present these strategies as options that can be considered as part of the planning process. We focus here on Wildfire, Flooding, Water Resources, and Agricultural strategies.

The communities in the Quad Cities area should make their own decisions about which strategies will be most beneficial and effective. To help in that process, a community-driven website, the Quad Cities Climate Action Hub (https://yavapaiclimatecoalition.org/climate-action-hub), has been created to provide a forum for sharing new projects and initiatives undertaken within the Quad Cities region by partnering organizations that will positively impact the issues raised in this Quad Cities Climate Profile.

Wildfire

Wildfire adaptation strategies include those related to emergency preparedness and individual risk reduction at the property level, as well as 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).

- To improve community emergency preparedness, communities in the Quad Cities region can participate in the Yavapai Firewise program (https://yavapaifirewise.org/), which teaches residents how to adapt to living with wildfire and encourages community members to take action to prevent future losses. Currently, 44 neighborhood organizations in Yavapai County are certified as Firewise Communities by the National Fire Prevention Association (NFPA).

- The Prescott Area Wildland Urban Interface Commission (PAWUIC) (https://yavapaifirewise.org/) is an organization in the Quad Cities area that helps communities prepare for and reduce the risk of wildfire. Increasing community engagement with programs like PAWUIC can help make more homes and neighborhoods resilient in the face of increasing wildfire risk.

- Strengthening and adding more *Firewise* and *Fire Adapted* communities in the Quad Cities area can enhance public health and safety goals such as the need for evacuation routes, zoning and land use that considers fire risk, firewise landscape treatments, partnerships and community engagement, and wildfire response.

- 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 (https://www.planning.org/publications/report/9174069/), 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.

- Encourage the use of firewise landscaping in and around the community, including in defensible space around homes and buildings. University of Arizona Cooperative Extension has compiled a list of plants that are suitable for use within defensible space, drought tolerant, and appropriate to areas above 3000 feet in elevation (https://cals.arizona.edu/extension/ornamentalhort/landscapemgmt/general/firewise.pdf). General guidance for plant selection includes:
  - Plants that shed their leaves or needles in extreme drought.
  - Drought-adapted plants that have smaller leaves or very succulent leaves that store water.
  - Salt tolerant plants that show natural fire resistance. A notable exception is salt cedar, which is highly salt tolerant but contains extremely volatile oils and burns very hot.

Flooding

Green infrastructure (GI) and low impact development (LID) (sometimes call *nature-based solutions*) are two well-established adaptation strategies to increase resilience to flood risk, and reduce reliance on scarce water resources for urban landscaping. Green infrastructure is an approach that uses plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters. Low impact development refers to systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration or use of stormwater in order to protect water quality and associated aquatic habitat.

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 (https://www.americanrivers.org/conservation-resource/value-green-infrastructure/) and Urban Land Institute's Harvesting the Value of Water report (https://uli.org/wp-content/uploads/ULI-Documents/HarvestingtheValueofWater.pdf) 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 (https://www.planning.org/publications/report/9131532/) uses the One Water approach to explore water supply, water quality, and stormwater holistically. The Subdivision Design and Flood Hazard Areas report (https://www.planning.org/publications/report/9112664/) offers practical local regulatory tools to review, inspect, and maintain flood risk across a variety of terrain and infrastructure needs, including:
    - Identify flood-prone areas to prioritize the installation of GI along the public right-of-way.

  - Assess and update zoning regulations, engineering standards, and stormwater management programs 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 (see firewise plant list on page 49).
  - 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 Quad Cities region include:
  - U.S. Environmental Protection Agency's Green Infrastructure: Low-Impact Development and Green Infrastructure in the Semi-Arid West (https://www.epa.gov/green-infrastructure/green-infrastructure-semi-arid-west)
  - 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) (https://www.fema.gov/flood-insurance) 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 serve as an 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) (https://msc.fema.gov/portal/home).
  - 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. Therefore, some infrastructure that is newly at-risk due to more extreme precipitation might not be included in current FEMA flood plain maps
  - A new tool that incorporates climate projections into flood risk assessments, developed by First Street Foundation (a non-profit research foundation), is available for public use: https://riskfactor.com/
  - 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.

Water Resources

As climate change begins to affect both water availability and quality communities can implement a number of strategies to protect and conserve their water resources.

- A number of GI approaches can contribute to groundwater recharge, thus helping to alleviate water availability issues. American Rivers has identified: tree planting, bioretention and infiltration (i.e. rain gardens, bioswales and wetlands), permeable pavement, and water harvesting (capturing rainwater for use on-site) as strategies that can increase groundwater recharge. (https://www.americanrivers.org/conservation-resource/value-green-infrastructure/)
- On a region-wide scale, watershed restoration and ecosystem management, such as practices proposed by the USDA Forest Service, can help to reduce threats to water quality and increase groundwater recharge by slowing runoff (https://www.fs.usda.gov/managing-land/sc/adaptation):
    - Target watersheds vulnerable to climate change for watershed restoration projects that improve the natural storage of water for municipal and agricultural uses.
    - Implement projects that improve watershed function and prepare streams, rivers, and other water bodies for extreme events, flooding, and changes in hydrology.
    - Support climate-informed reforestation and restoration, using climate decision support tools to assist in native seed sourcing and planting climate-adapted nursery stock where appropriate.

- The Alliance for Water Efficiency (https://www.allianceforwaterefficiency.org/) suggests several policies that can be used to support water-neutral community growth, such as:
    - Require new development to off-set water use through water conservation retrofits, rainwater harvesting, and stormwater capture.
    - Replace inefficient fixtures in existing buildings.

- Examples of water adaptation techniques proposed or underway in the Southwest can be found using the USDA Southwest Climate Hub Water Adaptation Techniques Atlas (https://webapps.jornada.nmsu.edu/wata/). The atlas is still in a development phase, but many examples are already available for review. There are three projects included from the Quad Cities region:
    - An Arizona Department of Transportation plan to build two dry wells connected to existing stormwater retention basins that will allow stormwater to recharge into the aquifer more quickly and reduce evaporation.
    - A concept plan for “macro rain-water harvesting” that would install a pipeline underground to transport water from the Lonesome Valley to Granite Creek by gravity, to enhance recharge and reduce evaporation.
    - Watson Woods Riparian Reserve Restoration, which used a grant from the Arizona Water Protection Fund to restore 4,100 feet of stream channel, along with planting of native riparian vegetation and native grasses and construction of

ephemeral wetlands off the main stream channel in the 126-acre preserve.

- The American Planning Association's Policy Guide on Water (https://www.planning.org/policy/guides/adopted/water/) addresses the growing need for collaborative approaches to community water planning. They recommend that communities use:
    - A planning practice that employs an integrated, systems-oriented, comprehensive approach to water management.
    - Innovative land-use planning and urban designs to improve and protect water environments.
    - New and improved professional practices to manage water more sustainably and equitably.
    - Awareness of the potential for inequity in access to water supply, water pricing that is not sensitive to ability to pay (and yet does not fully account for the full cost of water), and environmental justice issues where discharge of pollution to waterways occurs and where there is insufficient attention to flood mitigation.

Agriculture

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

- Increasing crop diversity, such as by introducing or increasing crops better adapted to heat or with lower water requirements.
- Where irrigation is necessary, shifting to best practices for arid environments (e.g., drip rather than flood or spray irrigation).
- 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.
- Participation in federal and state programs that support ranching or farming operations that combine agricultural productivity with natural resource conservation, such as the USDA's Natural Resources Conservation Service (https://www.nrcs.usda.gov/).
- Using livestock management strategies that can help to reduce vulnerability, such as:
    - Adjusting stocking rates
    - Implementing grazing management practices
    - Employing livestock bred for arid environments (such as Criollo cattle)
    - Erosion control along waterways
    - Use of alternate forage supplies

Plan Implementation

Climate adaptation planning can present opportunities for collaboration across traditional department silos as well as across 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 FEMA hazard mitigation plans (updated every five years) or municipal or county general plans (usually updated every ten years). The process of integrating climate change adaptation into existing planning processes is generally referred to as “mainstreaming” climate adaptation. Alternatively, adaptation plans strategies can be written as stand-alone plans. Stand-alone plans should be revised regularly as mitigation strategies succeed or as new challenges are recognized.

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. For example, it is important to review 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
- 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.

Additional Resources to Support Climate Change Adaptation Planning

The National Climate Assessment - Adaptation Chapter
https://nca2018.globalchange.gov/chapter/28/

National Oceanic and Atmospheric Administration's ***Implementing the Steps to Resilience: A Practitioner's Guide***
The book, with accompanying online resources, is designed to help climate adaptation practitioners work with local governments and community organizations to incorporate climate risk into equitable, long-term decision-making.
https://library.oarcloud.noaa.gov/noaa_documents.lib/OAR/CPO/Climate_Smart_Communities/Vol_06_ImplementingStepsToResilience.pdf

Arizona Department of Health Services
2017 Arizona Climate Health Adaptation Plan 2017 and 2018 addendum
https://www.azdhs.gov/documents/preparedness/epidemiology-disease-control/extreme-weather/pubs/arizona-climate-health-adaptation-plan.pdf
https://www.azdhs.gov/documents/preparedness/epidemiology-disease-control/extreme-weather/pubs/addendum-to-az-climate-health-adapt-plan.pdf

Climate Adaptation: The State of Practice in U.S. Communities
This report examines efforts to develop and implement climate-adaptation projects in 17 cities across the U.S. The study analyzed efforts underway, motivations for action and how communities went from planning to implementation.
https://kresge.org/resource/climate-adaptation-the-state-of-practice-in-u-s-communities/

Lincoln Land Institute of Land Policy's Planning for Climate Change in the West
This report highlights how local planners could implement land use–related practices and policies to take action against climate change impacts in their communities. The report offers tools and case studies, identifies barriers to local policy decisions, and provides recommendations for overcoming these obstacles to change.
https://resilientwest.org/2017/planning-for-climate-change-in-the-west/

First Street Foundation
Risk Factor tool maps fire, flooding, or extreme heat risk from climate change at a property level https://firststreet.org/risk-factor/

Quad Cities Climate Action Hub
A community-driven website created to provide a forum for sharing new projects and initiatives undertaken within the Quad Cities region by partnering organizations that will positively impact the issues raised in this Quad Cities Climate Profile.
https://yavapaiclimatecoalition.org/climate-action-hub

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.

Atmospheric rivers: narrow corridors of concentrated moisture in the atmosphere that lead to extreme precipitation events in the western U.S.

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).

El Niño Southern Oscillation (ENSO): El Niño and La Niña are the warm and cool phases of a recurring climate pattern across the tropical Pacific—the El Niño-Southern Oscillation, or "ENSO" for short. The pattern shifts back and forth irregularly every two to seven years, bringing predictable shifts in ocean surface temperature and disrupting the wind and rainfall patterns across the tropics.

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.

North American Monsoon (NAM): a seasonal change in the atmospheric circulation that occurs as the summer sun heats the continental land mass; as the summer heat builds over North America, a region of high pressure forms over the U.S. Southwest, and the wind becomes more southerly, bringing moisture from the Pacific Ocean and the Gulf of California. This circulation brings thunderstorms and rainfall to the monsoon region.

Pacific Decadal Oscillation (PDO): A sea surface temperature (SST) pattern in the North Pacific Ocean with warm and cold states, with longer cycles (decadal to multidecadal) than ENSO.

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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