CLIMATE PROFILE FOR

THE HIGHLANDS AT DOVE MOUNTAIN

Climate Profile for The Highlands at Dove Mountain

Climate Assessment for the Southwest (CLIMAS)
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Executive Summary

The earth's climate is changing. Global average temperatures have risen 1.8° F since 1901 (Wuebbles et al., 2017). 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.

Pima County is also experiencing climatic changes that will impact our temperatures, precipitation patterns, ecosystems, and human health and well-being. Changes for Pima County include:

Temperature

Average temperature

- The long-term average temperature for Pima County is 66.8° F. However, almost every year since 1985 has had average annual temperatures above the long-term average.
- These trends are projected to continue into the future. Average temperatures could be 2° F above the current average by 2030 and more than 10° F higher by the year 2100.

Extreme temperatures

- Since 1950, Pima County has averaged 15 days per year where the high temperatures reached above 105° F. The county could experience as many as 25 days above 105° F per year by 2030 and as many as 100 days per year by the end of this century.
- Minimum temperatures are also expected to rise. Since 1950, the county has averaged 3 days per year where the *minimum* temperature stayed above 80° F. By 2030 the county could see as many as 15 days per year where the minimum temperature is 80° F and by 2100 this number could be as high as 70 days per year.

Precipitation

Average precipitation

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

Extreme precipitation

- Over the past 30 years, the Southwest U.S. has experienced more extreme precipitation associated with monsoon thunderstorms. However, the frequency of such events has fallen, as has the average amount of monsoon precipitation.
- These trends of less frequent storms, decreased average precipitation, but more intense storms are likely to continue in the future.

- In severe storms, maximum wind gusts have become higher. Higher winds during severe storms are also projected to continue in the future, especially for areas across Southwest Arizona.

Impacts

Human Health

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

Water Availability

- Colorado River streamflow will likely be reduced in the future, due to higher temperatures, potential changes in precipitation, and reduced snowpack. Water levels in Lake Mead have been dropping since 2000, but reductions in water supply will not impact municipal deliveries for some time.

Wildfire

- Wildfire can pose a direct threat to people and structures as well as cause negative health impacts due to poor air quality. Future fire frequency could increase 25% in the Southwest, and the frequency of very large fires (over 12,000 acres) could triple.
- The Highlands at Dove Mountain is one of the moderate-risk communities in the wildland-urban interface of Pima County. The main wildfire threat comes from buffelgrass, an invasive species that outcompetes native desert plants.

Energy

- In the Southwest U.S., delivery of electricity may become more vulnerable to disruption due to increased demand for cooling and risks to transmission infrastructure from wildfires, among other reasons.

Real Estate/Demographics

- There is growing evidence that climate change will affect human migration patterns as some regions become less livable and people move to more viable regions, however there is not enough research about migration patterns specific to Arizona to be certain of trends and impacts at this time.

Climate Change Adaptation

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

Current Climate and Near-Term Trends

Annual Average Temperature

The long-term annual average temperature for Pima County (between 1895 and 2018) was 66.8° F. The hottest year was 2017 with an average temperature of 70.4° F and the coldest year was 1964 at 64.5° F. However, **almost every year since 1985 has had an average temperature above that long-term average**. In Figure 1, blue bars represent years with below-average temperatures and orange bars represent years with above-average temperatures.

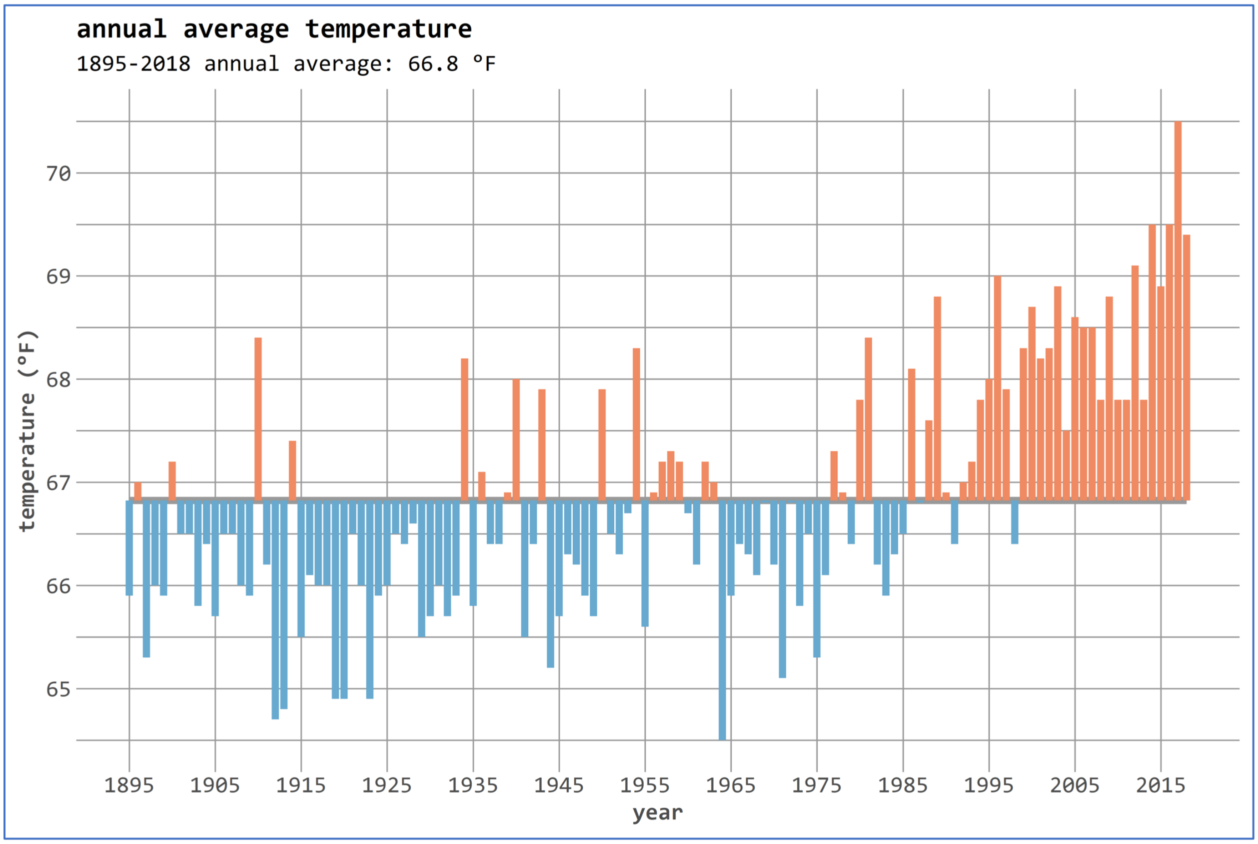

Figure 1: Annual average temperature for Pima County 1895 – 2018.

Disaggregating temperatures as average daily maximum, average daily minimum, as well as overall average allows us to identify patterns in the ways in which warming is impacting a region (Figure 2). *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. Overall average is the average of both maximum and minimum temperatures for an area over a given time. Figure 2 demonstrates that both maximum and minimum temperatures are rising in Pima County, meaning **our high temperatures are getting hotter and our cool temperatures are not getting as cool as in the past**.

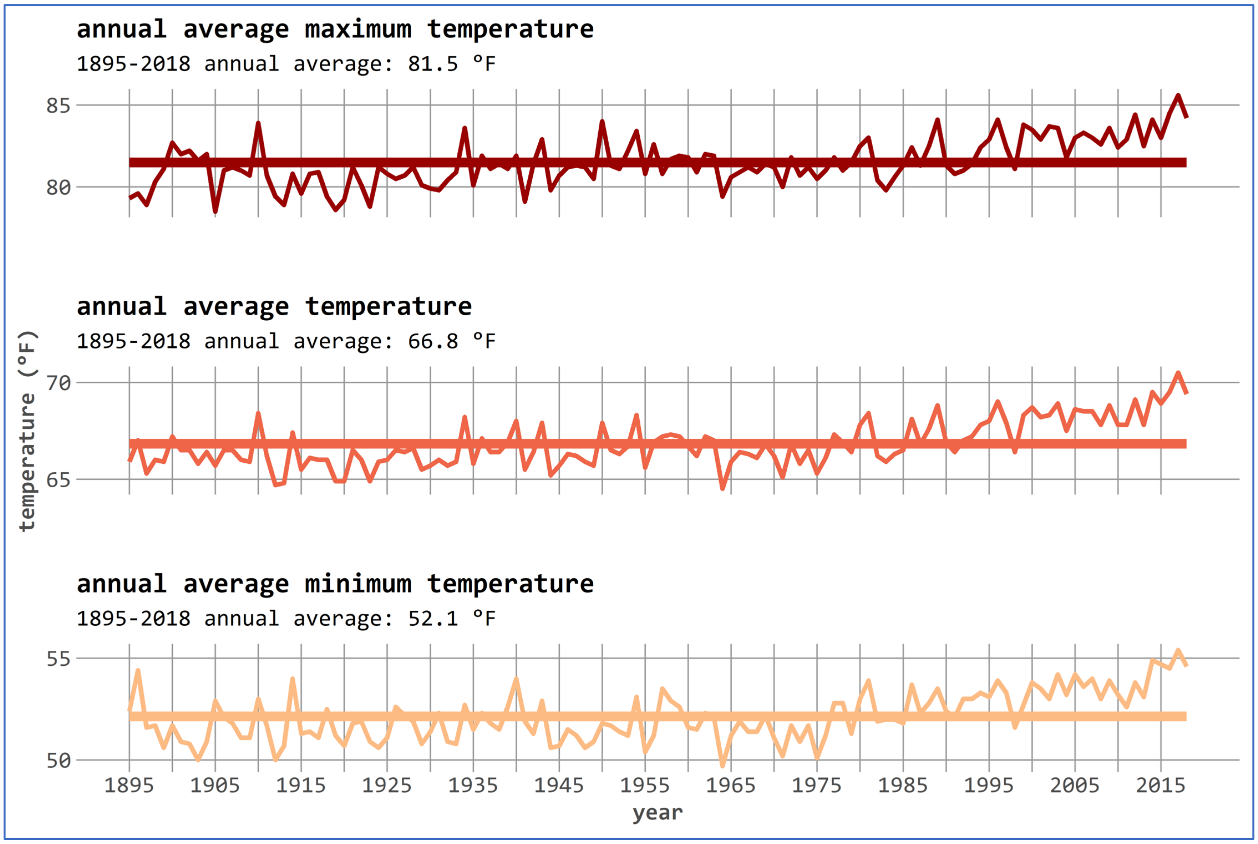

Figure 2: Annual average maximum (red), minimum (tan), and overall average (orange) temperatures for Pima County from 1895 – 2018.

Annual Average Precipitation

The long-term average annual precipitation amount for Pima County is 12.1 inches. Precipitation in the Sonoran Desert is naturally variable from year-to-year, as Figure 3 shows. In Figure 3 blue bars represent years with above-average precipitation and brown bars represent years with below-average precipitation. The driest year was 1956 with 6.1 inches and the wettest year was 1982 with 24.2 inches – twice the average amount of precipitation. **Arizona has been in a drought since 1999, with almost every year since then experiencing below-average precipitation**.

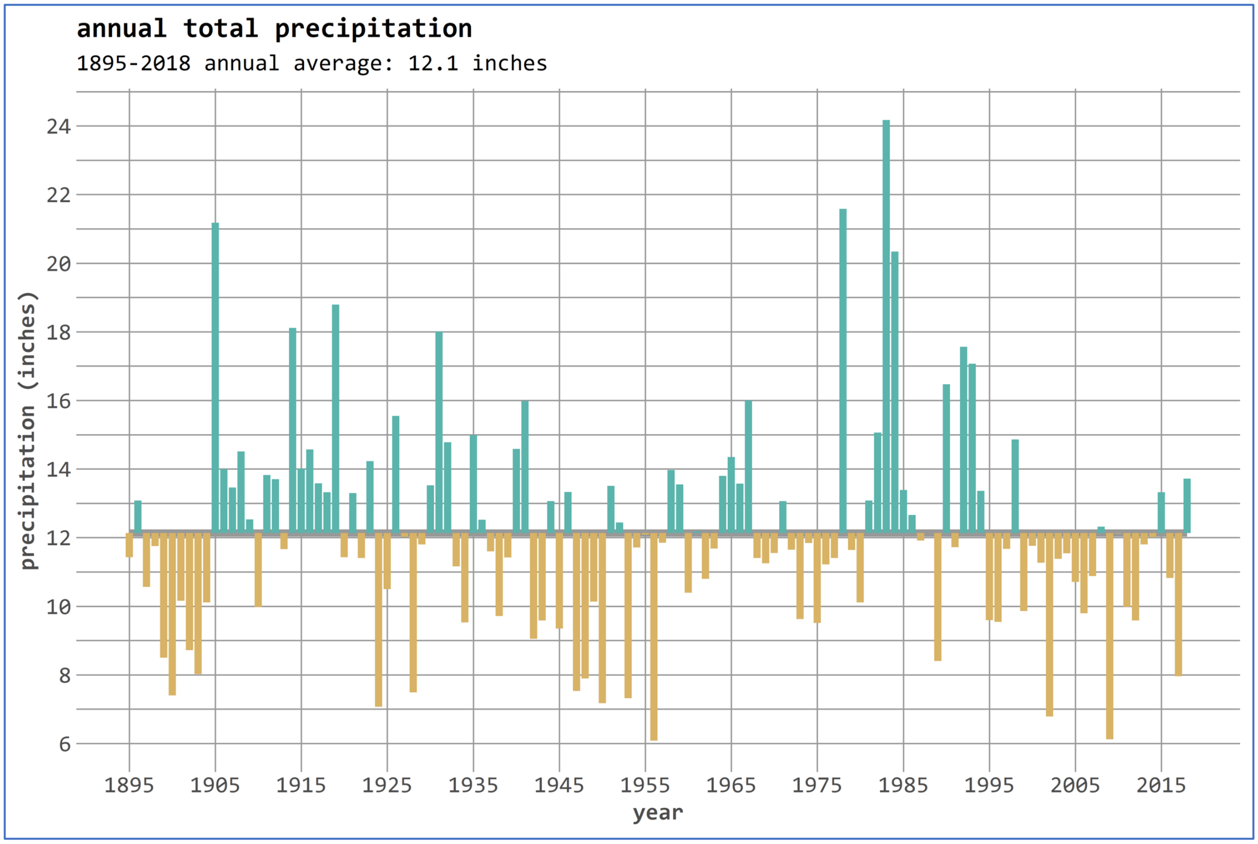

Figure 3: Annual total precipitation for Pima County 1895 – 2018.

Future Temperature and Precipitation Projections for Pima County

The Intergovernmental Panel on Climate Change (IPCC), which is the international body convened to assess climate changes and impacts across the globe, has developed a set of four 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 based on the current rates of GHG emissions and estimated emissions up to 2100, based on assumptions about global levels of economic activity, energy sources, population growth and other socio-economic factors. These scenarios are then used in Global Climate Models (GCMs) to estimate future global average temperatures.

GCMs cannot firmly predict future climate patterns, but they are useful tools that point us toward likely futures, based on the best currently available science. There are two main sources of uncertainty regarding climate projections that should be kept in mind when considering future climate scenarios. First, there is a range of possible ways humans will choose to manage our emissions of GHGs in the future. The four different RCPs are one way to explore these different possible emissions scenarios and generate climate projections for each one. A second source of uncertainty is the ability of the GCMs to capture the complex global climate system. No single climate model can perfectly imitate such a complex system. For example, climate scientists tend to trust models to project the *direction* of change (such as temperatures rising), but they have less confidence in the ability of models to project the ***magnitude of change*** (exactly how much temperatures will rise). The approach to reducing this source of uncertainty is to use the average projections from many different models rather than rely on any single model.

The following summaries of projections – both for the globe and for Pima County – use RCP 4.5 and 8.5 (defined in Table 1 with the other RCPs) and an average of multiple climate models to reduce uncertainty and provide reasonable estimates of possible future climates for both scales of analysis. We chose to use RCP 4.5 because it is a reasonable, but low estimate of future emissions. RCP 8.5 is the scenario closest to our current emissions use. Table 1 summarizes the assumptions and projections for all four RCPs, which are represented in Figure 4.

Figure 4 shows the projected global temperature increases using the four RCPs. The green line that runs from 1900 (far left of the timeline) through 2014 represents the observed global average temperature for that period of time. The shading around each solid line represents the range of results from the multiple GCMs that are used to generate the average projections (solid lines). RCPs 2.6 and 8.5 are shown as lines on the graph and bars to the right, whereas RCPs 4.5 and 6.0 are only shown as bars on the right. Although there is a range of possible temperatures for each scenario, they are all projecting rising temperatures.

Table 1. Assumptions and Projections for each Representative Concentration Pathway, represented in Figure 4.

Scenario	**Assumptions**	**Projected Temperature Increase**
RCP 2.6 *blue line and shading*	"Best Case Scenario" - assumes that through policy intervention, GHG emissions are reduced by 2020 and decline to around zero by 2080, leading to a slight reduction in today's GHG levels by 2100.	Global average temperature increase of 2.5° F (1° C) by the year 2100.
RCP 4.5 *aqua bar shown only to the right of the chart*	Assumes that GHG emissions will peak at around 50% higher than year 2000 levels in about 2040 and then fall.	Global average temperatures increase of 4° F (1.8° C) by 2100.
RCP 6.0 *yellow bar shown only to the right of the chart*	Assumes that emissions will double by 2060, then fall but still remain above current levels through 2100.	Global average temperature increase of 5° F (2.2° C) by 2100.
RCP 8.5 *red line and shading*	"Worst Case Scenario" - Assumes GHG emissions continue to grow at current rate through 2100.	Global average temperature increase of more than 8° F (3.7° C) by 2100.

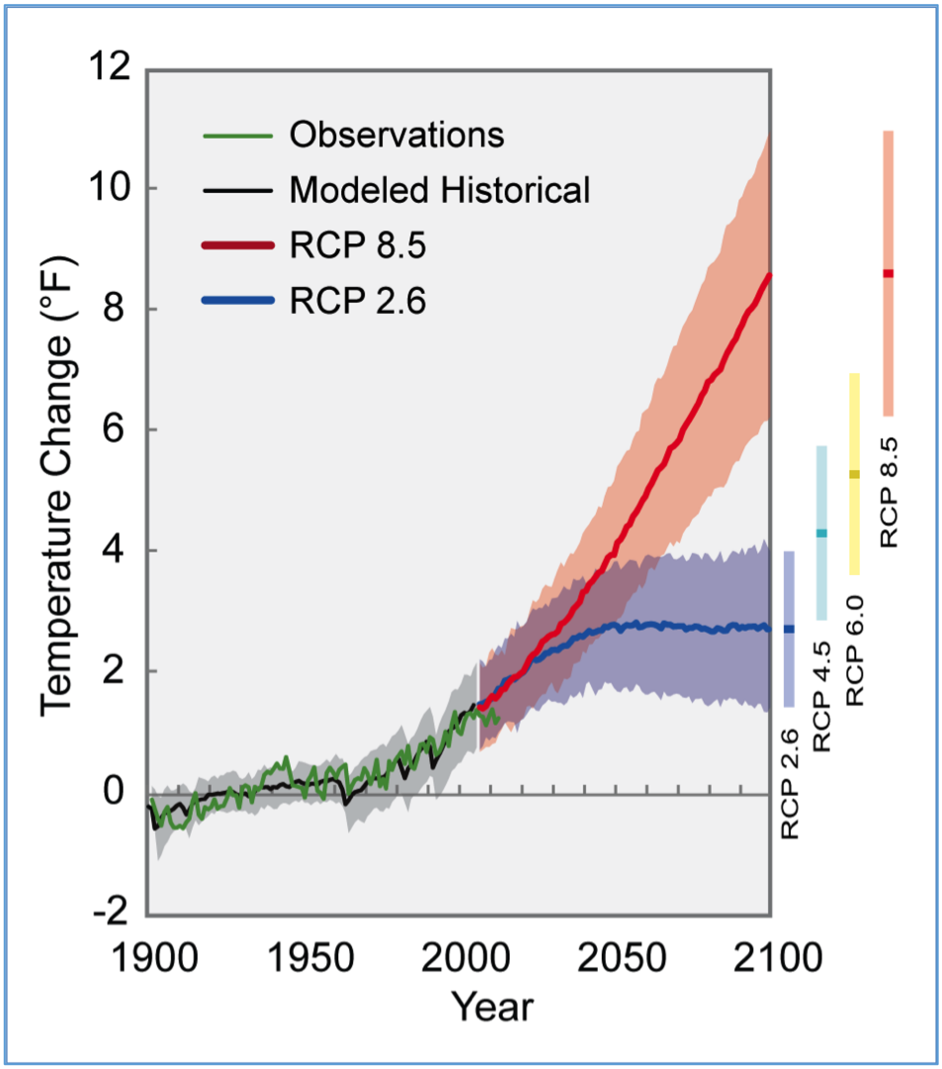

Figure 4: Projected global temperature increases using the four Representative Concentration Pathways (RCP) scenarios. Source: https://nca2014.globalchange.gov/report/our-changing-climate/future-climate-change.

GCMs that were built to cover the whole globe can be focused on smaller regions through a process of downscaling. We used statistically downscaled climate models to compile climate projection data for Pima County, which is a small enough area to capture the trends expected to affect the county, but big enough that we have confidence in the accuracy of the projections. In this study, we analyzed downscaled climate projection data from one model run of 30 different global climate models using two of the scenarios described in Figure 4 – RCP 4.5 and RCP 8.5. At present, RCP 4.5 represents an optimistic, lower-emissions scenario, while RCP 8.5 is closer to our current, higher emissions trajectory.

Projected Changes to Annual Average Temperature

An average of climate model **projections for Pima County indicate that annual average temperatures may rise 2° F by 2030, compared to about what temperatures were in the year 2000, with continued increases (as much as 10° F above the long-term average) by 2100**. Such changes could make the annual average temperature approximately 69° F by 2030 and possibly 77° F by 2100. In Figure 5 the red line represents a high greenhouse gas emissions scenario (RCP 8.5). The orange line represents a moderate scenario (RCP 4.5).

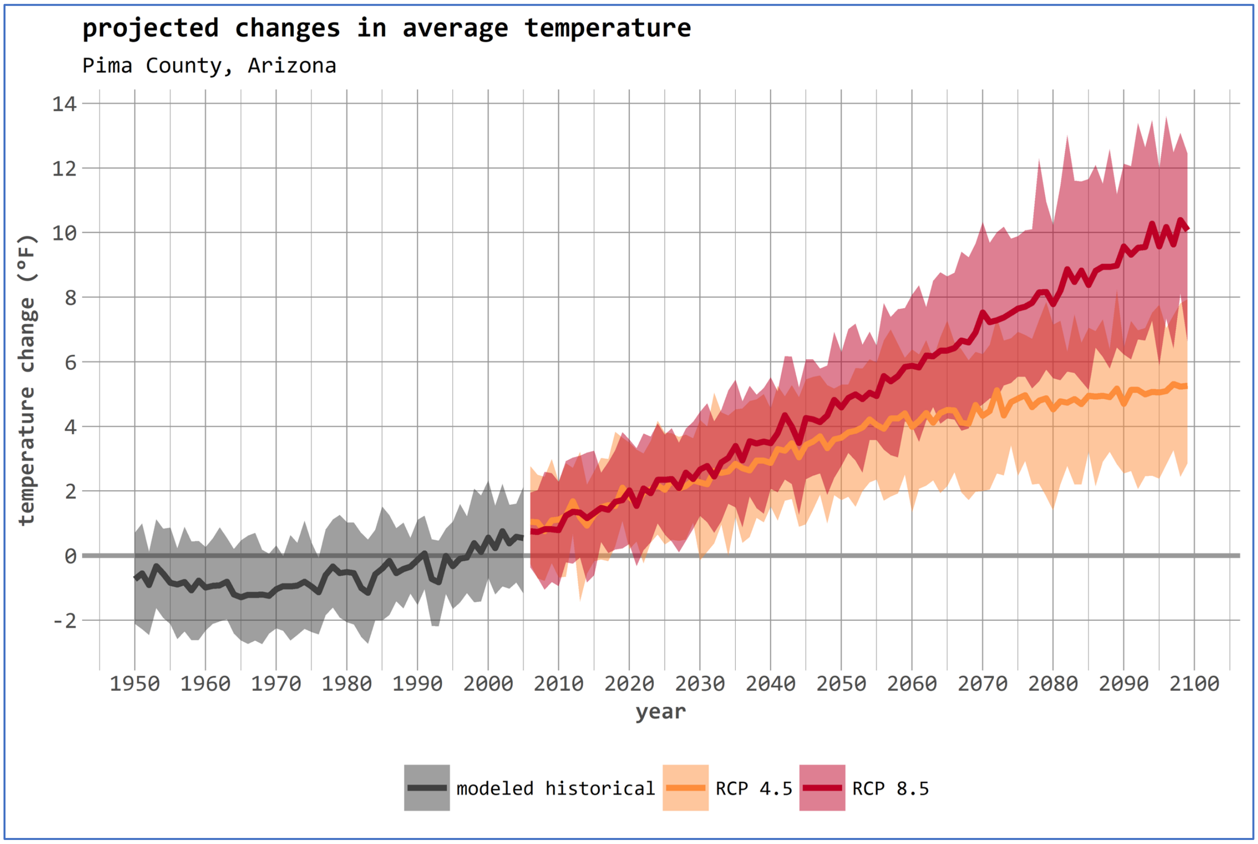

Figure 5: Projected changes in average temperature for Pima County. RCP 8.5 is a high emissions scenario, and RCP 4.5 is a moderate scenario (see Table 1). The gray line and shaded area represent historical temperatures, as simulated by the climate models.

Projected Changes to Annual Average Precipitation

It is very difficult to project future precipitation changes in this region because it has been challenging to accurately model the behavior of the North American monsoon (NAM). The NAM accounts for approximately half of our annual precipitation, meaning that the inability to capture its dynamics in climate models leads to high uncertainty about model projections. However, the best available projections show some possible decreases in precipitation by the end of the century, with a likely continuation of our natural year-to-year variability. In Figure 6 the dark blue line represents RCP 8.5 (worst-case scenario) and the light blue line represents RCP 4.5, the moderate scenario. Given the uncertainty of these projections, **many climate scientists in this region recommend assuming that annual average precipitation will remain relatively consistent, with year-to-year variation as we see now**.

Although the annual average precipitation in this region may change very little, **the higher temperatures will accelerate evaporation and transpiration from plants, resulting in less surface water and drier soils**.

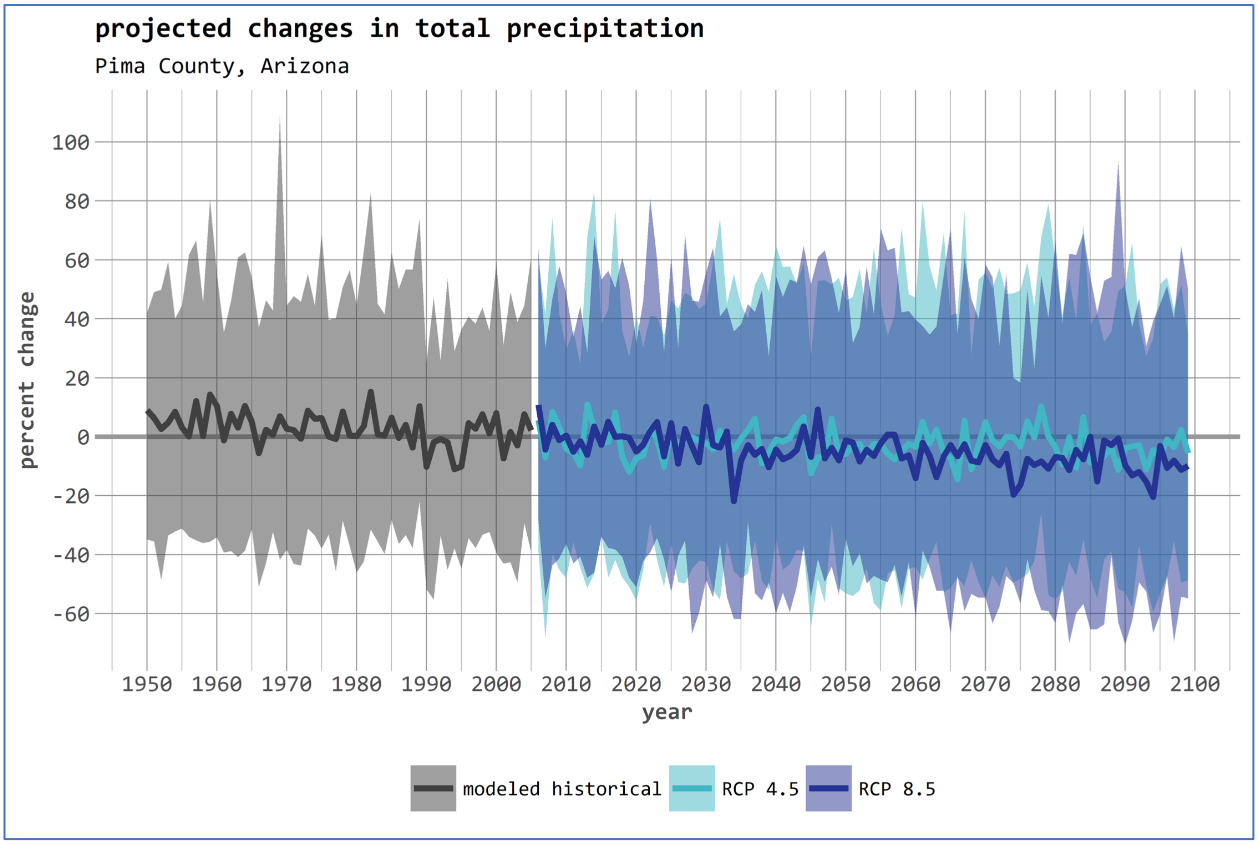

Figure 6: Projected changes in total precipitation for Pima County.

Projected Changes in Extremes of Temperature and Precipitation

Temperature

Since 1950 Pima County has had an average of 15 days each year where temperatures reached over 105° F. In Figure 7, dark gray bars show observed annual average temperatures from 1950-2013. The horizontal line from which bars extend represents the overall average from 1961-1990 (a 30-year period of record is the standard unit for making climatological comparisons). Bars that extend above the line show years with an above average number of days warmer than 105° F. Bars that extend below the line were below average. **Since the early 1990s, almost every year has had more days above 105° F than the 1961-1990 average**. This trend is also expected to continue, based on climate model projections for the region. **By 2030, the county could see as many as 25 days per year above 105° F**. By 2100, between 50 (RCP 4.5) and 100 (RCP 8.5) days per year may hit high temperatures above 105° F, depending on the greenhouse gas emissions scenario.

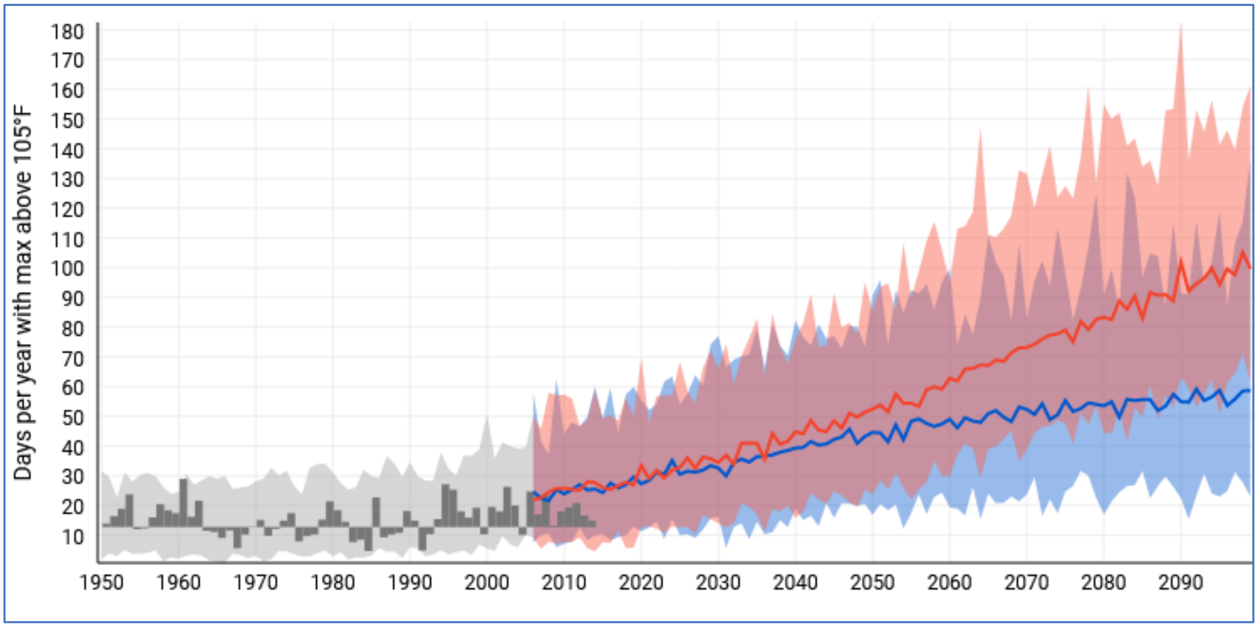

Figure 7: Days per year with maximum temperatures above 105° F. RCP 4.5 is shown as the blue line and shaded area, and RCP 8.5 is shown as the red line and shading.

The number of days per year where the minimum temperature stays above 80° F has also been increasing. **Almost every year since the mid-1990s has had more days per year with minimum temperatures above 80° F than average**. This trend is projected to continue, and **by 2030 the county could see as many as 15 days per year where the minimum temperature does not drop below 80° F**. By 2100, this number could be as high as 70 days per year.

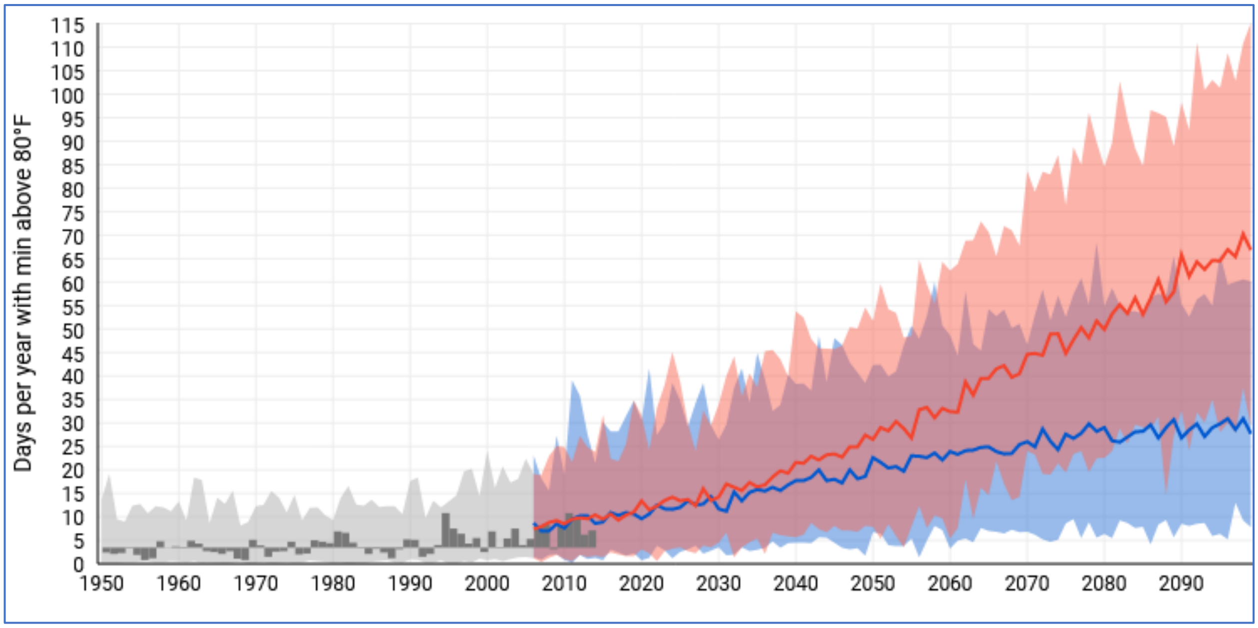

Figure 8: Days per year with minimum temperatures above 80° F. RCP 4.5 is shown as the blue line and shaded area, and RCP 8.5 is shown as the red line and shading.

Similarly, the number of days each year with minimum temperatures below 32° F are declining. Between 1961 and 1990, temperatures in Pima County dipped below freezing an average of 24 days per year. However, since the late 1970s, most years have not reached that average. We expect this trend to continue, with **as few as 20 days per year with minimum temperatures below 32° F by 2020** and as few as 5 days per year by 2100.

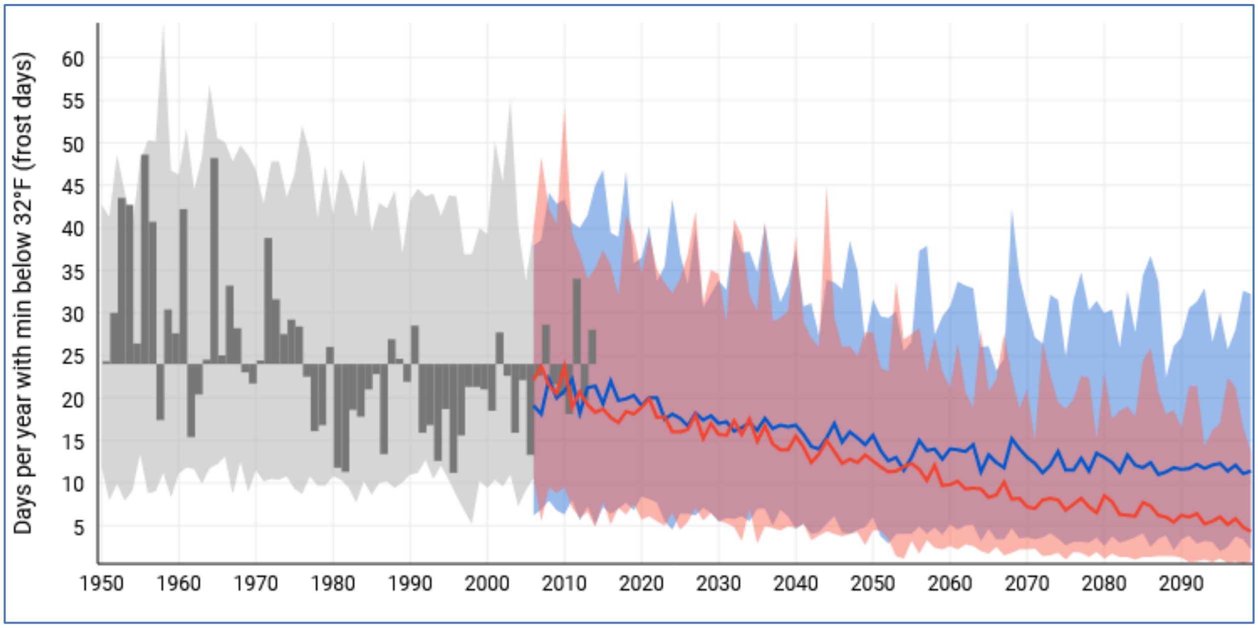

Figure 9: Days per year with minimum temperatures below 32°F. RCP 4.5 is shown as the blue line and shaded area, and RCP 8.5 is shown as the red line and shading.

Changes in Monsoon Events

The monsoon storms that bring Pima County half its precipitation each year are also changing in ways that are likely to affect drought conditions, flood regimes, and storm-related hazards. Over the past 30 years, the Southwest U.S. has experienced more extreme precipitation associated with monsoon thunderstorms. **Rising summer temperatures are intensifying rainfall because warmer air can hold more moisture** and create conditions that favor heavy precipitation from convective storms (Luong et al., 2017). **In severe storms, maximum wind gusts have become higher**. Higher winds during severe storms are also projected to continue in the future, especially for areas across Southwest Arizona (Luong et al. 2017; Castro 2017).

However, **the frequency of such events has fallen, as has the average total amount of monsoon precipitation** (Castro, 2017). The change in frequency is due to changes in the regional weather pattern at this time of year. The monsoon ridge – an area of high pressure over the Southwest – has expanded and intensified (higher pressure) over recent decades due to the regional warming trend. This has made it more difficult for thunderstorms that form over high elevation, mountainous areas to move into the low-elevation deserts (Lahmers et al., 2016). With a larger and stronger monsoon ridge, southern Arizona – including The Highlands at Dove Mountain – is no longer on the edge of the ridge where inverted troughs—the main atmospheric feature that allows convective storms to cluster—typically tracked (Figure 10). Inverted troughs now are more commonly moving from east to west farther to the south. These trends—less frequent storms, decreased average precipitation, but more intense storms—are likely to continue in the future.

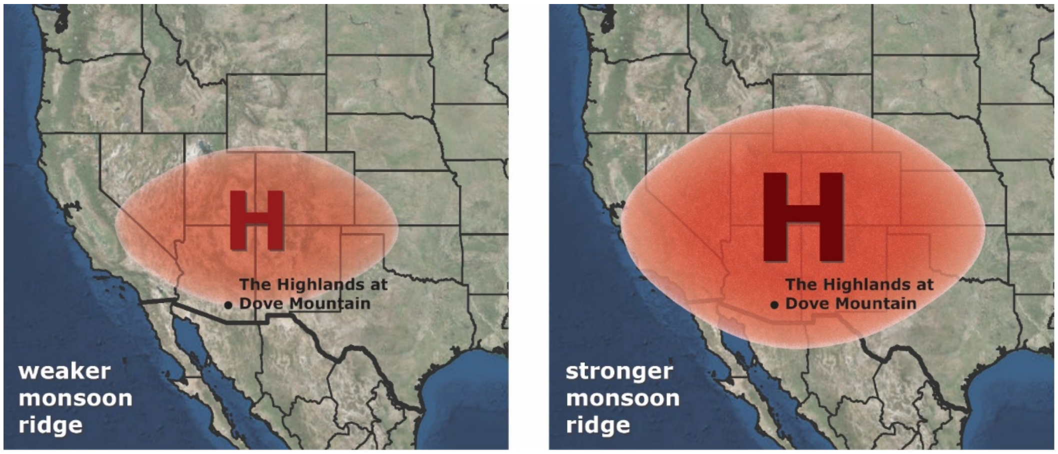

Figure 10: The stronger monsoon ridge, which has been occurring in recent years, has reduced the frequency of storms in Pima County. However, when storms occur they are now more intense than in the past.

Impacts

Human Health

Heat

Extreme heat events (EHEs) are a concern in Pima County. Since 2012, there have been 63 injuries and 8 deaths attributed to heat events in Pima County. For example, June 2017 was the hottest June on record for Tucson, with an average monthly temperature of 89.7° F. During the month there was a 3-day heat wave, with temperatures at Catalina State Park reaching 114-115° F on all 3 days, all of which set the record high for the day. EHEs can impact public safety in two ways. First, there are direct impacts on human health. Extreme heat places greater stress on the body, especially when combined with humidity (Brown et al., 2013). Older adults, children, those who work outside, those with chronic illnesses, and those who are socially isolated tend to be at greater risk. Nighttime temperatures are particularly important, since the human body needs the relief of the cooler nights to reduce the stress from daytime heat. Nighttime temperatures have been increasing faster than daytime temperatures, so it will become increasingly important in the future to find ways to cool off at night during the heat of the summer. Second, high heat events can strain energy grids as residents increase their use of air conditioning to stay cool. If residents lose power, there will be an increase in human health impacts.

In addition to the human health effects of heat, there can be additional burdens placed on our natural resources. An example of the links between heat and water use comes from a study of the effects of the urban heat island (UHI) in Phoenix. A UHI is an urban or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities. The study found that the more an area was affected by the UHI—specifically if the low temperature in the neighborhood was higher than other areas of Phoenix—the more water was used by households in that neighborhood. A 1° F increase in a neighborhood's low temperature increased water use per household by 290 gallons per month (Guhathakurta and Gober, 2007).

Air quality

Climatic changes are also affecting air quality, with implications for human health. 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. The overall rise in air pollutants associated with climate change is expected to contribute to rising rates of asthma and other allergic diseases (Crimmins et al., 2016).

Increased temperatures will increase ground-level ozone pollution in many areas of the United States. Ground-level ozone is produced when nitrogen oxides and hydrocarbons from automobile exhaust, power plant and industrial emissions, gasoline vapors, chemical solvents, and some natural sources react in heat and sunlight. Exposure to ground-level ozone is linked to reduced lung function and respiratory problems such as pain with deep breathing, coughing, and airway inflammation (Brown et al. 2013). Ozone exceedance days have fallen in Pima County since the early 2000s (Figure 11). However, ozone tends to peak in the hotter summer months – May through August (Figure 12). As temperatures rise and heatwaves become more common, it is possible that ozone exceedance days may also rise.

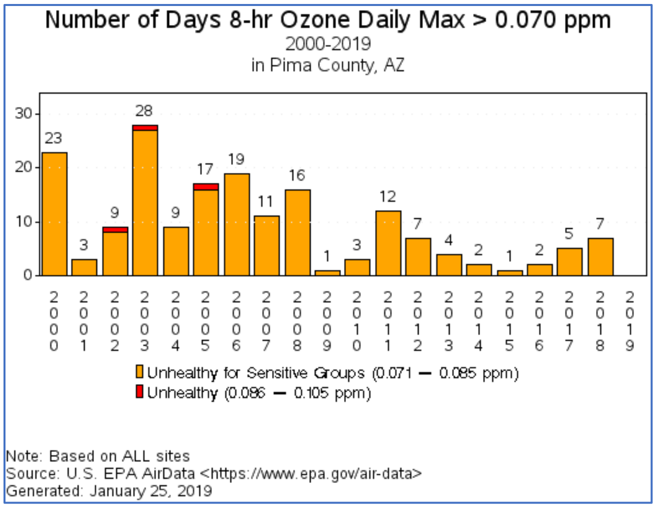

Figure 11: *Number of days ozone levels have exceeded 0.07 parts per million (ppm), which is unhealthy for sensitive groups; 0.086 ppm, which is unhealthy for all; and 0.106, which is very unhealthy for all, in Pima County since 2000.*

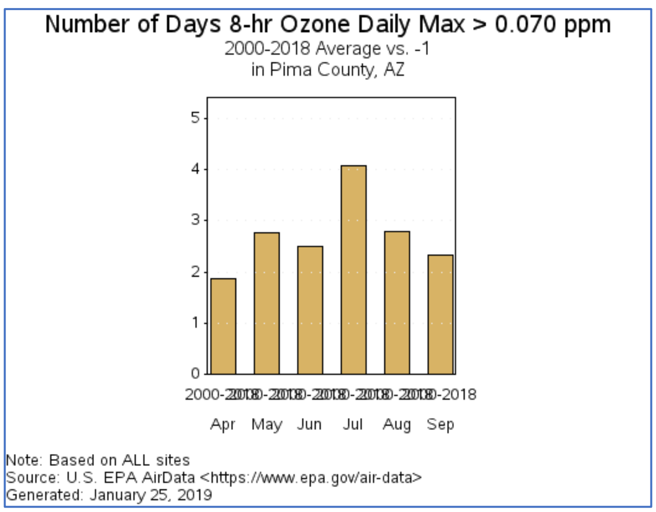

Figure 12: *Average number of days from 2000 to 2018 in which ozone exceeded 0.070 ppm in each month. May – August, the warmest months, also had the highest number of high ozone days.*

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

In Pima County, PM10 pollution often comes in the form of dust storms. Dust storms tend to peak during the spring months in the Southwest, due to stronger winds from changes to the jet stream as the temperatures warm in the spring. Dust storms have been occurring more frequently and over a longer season in recent years in Arizona due to drought conditions (Figure 13) (Tong et al., 2017). The decade of the 2000s saw significantly more dust storms than the 1990s (Tong et al. 2017). Dust from unpaved roads, construction sites, fires, and abandoned fields combined with smog, soot, smoke and ash can enter the nose and lungs and create serious health problems.

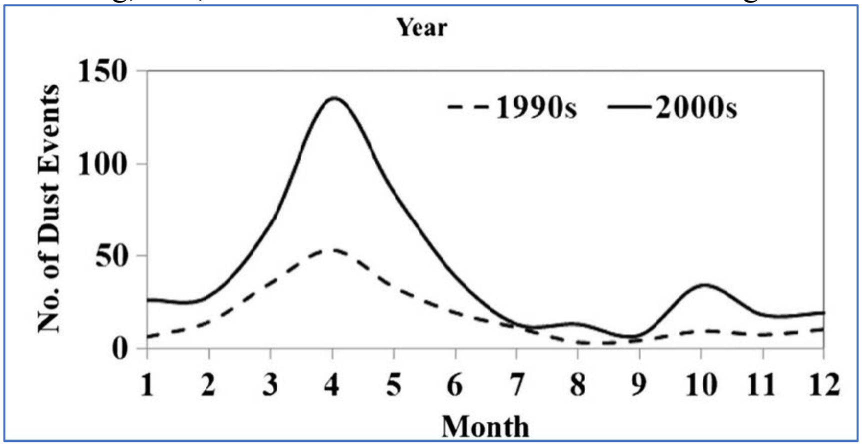

Figure 13: Monthly distribution of dust events across the Western United States in the 1990s and 2000s.

Flooding

Although overall precipitation in Pima County may remain steady or decline slightly, individual precipitation events may become more extreme due to the ability of a warmer atmosphere to hold more water (Gershunov et al., 2013) and changes to the NAM (discussed above). Areas in and around the community that are already flood-prone may experience larger floods. Areas that do not regularly flood now could become flood-prone with larger storm events. More intense flooding means that residents need to be even more diligent about not crossing flooded washes, and the community should consider adaptation options to combat flooding impacts (see Adaptation Strategies section below).

Vector-borne diseases

Climate change seems likely to affect certain vector-borne diseases like West Nile Virus (WNV) because warmer temperatures will create a more welcoming environment for the mosquitos that carry WNV.

The mosquito that carries WNV are the *Culex tarsalis* and *Culex quinquefasciatus.* Warming temperatures across the U.S. are expected to lead to a spread of WNV. However, certain areas may experience an increase, while others may experience a decrease (Roach et al., 2017). Climate change is likely to 1) lengthen the season during which mosquitos can survive and breed, and 2) 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.

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

Mental health

Many people exposed to climate-related disasters, such as flooding, heat, and wildfire, experience serious mental health consequences, such as post-traumatic stress disorder, depression, and general anxiety, which often occur simultaneously. This is especially true of events that involve "loss of life, resources, or social support and social networks or events that involve extensive relocation and life disruption." 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.

Additionally, clinical depression has been observed in patients infected with WNV. Some studies have shown a connection between higher temperatures and suicide rates.

Food security/prices

Climate change has the potential to disrupt food availability if supply routes and processing facilities are disrupted (Brown et al., 2015); crop yields change due to changes in temperature or drought conditions (Hatfield et al. 2014); climatic changes shift or change the land area available for agriculture (Takle et al. 2013); hotter nighttime temperatures increase the heat stress on livestock (Hatfield et al., 2014; Mader, 2012); or changing moisture and temperature impact disease distribution and proliferation among livestock (Gaughan et al., 2009).

The U.S. food system is connected to the worldwide food system. The U.S. imports about one-fifth of its food from international markets, making our food supply susceptible to climatic changes in other parts of the world (Hatfield et al., 2014). Southern Arizona imports the bulk of its agricultural crops from California and Mexico. The bulk of staple crops (corn, rice, wheat, and soy) as well as beef and dairy products are grown in the Midwest (Hatfield et al., 2014; Takle et al., 2013).

Current research into U.S. agriculture production shows that climate change is unlikely to affect food security until at least 2050 (Takle et al., 2013). The complexity and international reach of the food system in the U.S. supports many intervention points to help reduce the impacts on people and communities (Brown et al., 2015).

Ecosystem Changes

Increased minimum temperatures, combined with a decrease in freezing temperatures and a lengthened frost-free season, will likely lead to an expansion of the boundaries of Southwestern deserts to the north and the east, migration of plant communities to higher elevations, susceptibility to insect infestations and pathogens, and establishment of invasive annual grasses (Archer and Predick, 2008; Sonoran Desert Network Inventory and Monitoring Program, 2010). As these plant communities move further upslope, species that currently live on "Sky Island" mountain tops would have no higher habitats in which to migrate (Archer and Predick 2008; Sonoran Desert Network Inventory and Monitoring Program 2010). Plants and animals in arid regions already live near their physiological limits, and small changes in temperature and precipitation will change the distribution, composition, and abundance of species (Archer and Predick 2008).

For example, warmer temperatures will decrease populations of velvet mesquite (*Prosopis velutina*) and increase some cactus species (Munson et al., 2012). The range and abundance of saguaros, however, will potentially decline due to drought and reduced native perennial grass and shrub cover (Archer and Predick, 2008). Saguaros are tolerant to high, but not extreme, temperatures. Past studies of saguaro only looked at freeze thresholds, but climate change and global warming have prompted more research on heat thresholds. Long-term periods of drought may affect saguaros. Drezner (2014) found that soil and higher temperatures have more influence over saguaro mobility and mortality than does moisture. Research also found that wildfires are the biggest threat to saguaros.

Wildfire can cause saguaro mortality up to 10 years after the fire (Narog and Wilson, 2013). Springer et al. (2015) found that saguaro exposed to fire tried to re-establish in higher elevations, away from the areas where fires had occurred. Fire destroys habitat required for saguaro to reproduce and mature (Drezner, 2014). Fire also affects saguaro reproduction because they grow slowly and are not prolific seeders. Seedlings are damaged or destroyed by fire and are out-competed by non-native seedlings for light, moisture, and soil nutrients (Rogers, 1985).

Fire is also a threat to other cacti. Cacti have thin, exposed epidermal layers where photosynthesis and respiratory functions take place. This exposed layer makes cacti easily damaged, exposing the cacti to insect attack, disease infestation, and death (Thomas, 1991). Fire also burns the spines of cacti, leaving the cacti unprotected from herbivory.

Dry desert shrubs and non-native grasses can start wildfires. Creosote bush, which offers protection to infant saguaros, becomes extremely flammable during dry years. Invasive grasses, including buffelgrass, are highly flammable.

Infrastructure

The intense rainfall and associated flooding and extreme heat we expect to occur due to climate change puts our transportation infrastructure at risk (Jacobs et al., 2018). High temperatures can stress bridge integrity, increase wear on roads, and hinder air transportation when temperatures are too hot for safe take-off. Climate change is projected to increase the costs of maintaining, repairing, and replacing infrastructure, with regional differences proportional to the magnitude and severity of impacts. Nationally, the total annual damages from temperature- and precipitation-related damages to paved roads are estimated at up to $20 billion under RCP8.5 in 2090 (in 2015 dollars) (Jacobs et al., 2018).

Roadways are one example of infrastructure impacts. With extreme temperatures, paved roads can become rutted, cracked, and buckled (Jacobs et al., 2018). Engineering protocols in the U.S. are based on stationary climate assumptions and are currently pegged to climate data from 1964 – 1995 (Underwood et al., 2017), meaning that roadways may not be made of materials sufficient to withstand the climate-related stresses expected in the coming decades. In fact, Underwood et al. (2017) found that asphalt grades are already being improperly determined in many parts of the United States. In order to understand the impacts to any one community, it is necessary to identify what grade of asphalt is currently used, whether that grade can withstand expected temperature increases, the linear miles of roadway affected, and the cost to upgrade road surfaces using higher grade materials.

Water availability

Although water resources in the western U.S. are being affected by rising temperatures, earlier snowmelt, more rain and less snow, and changes in storm tracks, total annual precipitation has not changed significantly (Udall, 2013). Studies of the Colorado River indicate that for every 1° F of warming there is a decrease in streamflow at Lees Ferry (where Colorado River flows are measured) of 2.8-5.5 percent (Udall 2013). The same study also indicates that even if temperatures do not change, changes in precipitation are magnified in the Colorado River system in such a way that a one percent change in precipitation (either up or down) changes runoff by one to two percent (Udall 2013). An additional stressor on Colorado River water is the effect of dust on snowpack in the region, which can reduce runoff from snowpack by up to five percent (Udall 2013).

These potential physical changes to the amount of runoff in the Colorado River system is in addition to a pre-existing stressor: the river is over-allocated and in a structural deficit stemming from a combination of losses from evaporation and water use (Central Arizona Project, 2014). The water usage in the lower basin—Arizona, California, and Nevada—is 1.2 million acre feet (AF) greater than the inflows to Lake Mead (located on the Arizona and Nevada state line) that supply the region.

Water levels in Lake Mead have been dropping since 2000 (Central Arizona Project, 2014). To address the deficit, in 2007 the lower basin states agreed to a set of interim guidelines intended to run through 2026. These guidelines were designed to provide greater certainty for water users during times of shortages in Lakes Mead and Powell by creating a series of thresholds and related reductions to water deliveries to guide decisions about water delivery (Jerla and Prairie, 2009). The delivery reductions will take place when the water level in Lake Mead reaches three different thresholds: 1,075 feet above mean sea level (amsl), 1,050 amsl, and 1,025 amsl. One thousand feet amsl is considered the critical level for Lake Mead when both water and energy availability are at risk. If Lake Mead falls to the critical 1,000 feet amsl level, the Secretary of the Interior will consult with the basin states to discuss further measures. Each threshold will trigger a tier reduction.

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

The first shortage declaration, at the Tier 1 level, is expected in 2020. In response, the Colorado River basin states have prepared drought contingency plans (DCP) intended to prevent the kinds of cuts required by a Tier 2 shortage (Lake Mead reaching 1050 feet amsl). Arizona's portion of the DCP relies on voluntary cuts to CAP water use by farmers, who will receive financial support to help them switch to groundwater for irrigation; payments to the Gila River Indian Community and Colorado River Indian Tribes in return for them leaving water in Lake Mead; and some loosening of Arizona's groundwater management rules. The DCP was approved in April 2019.

The City of Tucson Water Department has a Drought Preparedness and Response Plan, that was last updated in 2017. The Tucson Water service area is currently in a Stage 1 drought declaration, and will likely move to Stage 2 if the Bureau of Reclamation declares a Tier 1 reduction of CAP water (City of Tucson Water Department, 2006). Table 2 outlines the response actions that will be asked or required of reclaimed water users for each drought stage.

Table 2: Response actions that reclaimed water users will be asked or required to do to reduce water demand during drought response Stages 1 through 4 (City of Tucson Water Department, 2006).

Stage 1	• Continue customer education on efficient-water-use especially related to drought conditions • Voluntary self-audits and developing water budgets to potentially gain exemptions from mandatory reductions in advanced drought response stages • Tucson Water staff prepares a methodology to monitor wastewater treatment plant flows and calculate reclaimed water customer reductions for later drought stages if approved water budgets are not implemented
Stage 2	• Continue Stage 1 measures • Prepare customers for potential reductions if wastewater flow reductions occur and if an approved water budget is not implemented • Potable water will not provide backup supplies to the reclaimed water distribution system

Stage 3	• Implement all Stage 1 and 2 measures and may include:
	    • Require irrigation restrictions, with potential exemptions for sites that have conducted audits, upgraded systems to meet minimum efficiency standards, and irrigate with budget-based irrigation schedules
	    • Require signage for facilities that implement budgets stating they are in compliance with current drought restrictions
	    • Potable water will not provide backup supplies to the reclaimed water distribution system

Stage 4	• Continue Stage 1, 2, and 3 measures

Wildfire

Wildfire can pose a direct threat to people and structures as well as cause negative health impacts due to poor air quality. Climate change has driven an increase in the area burned by wildfire in the western U.S. by increasing temperatures and drying forests, shrublands, and grasslands, making them more susceptible to burning. Climate models indicate that future fire frequency could increase 25% in the Southwest, and the frequency of very large fires (over 12,000 acres) could triple (Gonzalez et al., 2018).

Dove Mountain is one of the moderate-risk communities in the wildland-urban interface, according to the Pima County Community Wildfire Protection Plan. The wildfire threat to Dove Mountain comes from the desert wash/xeroriparian corridor and creosote bush-bursage desert scrub types, with paloverde-mixed cacti desert scrub and mesquite upland associations found at foothills of the Tortolita mountains. An additional threat comes from buffelgrass (*Cenchrus ciliaris)*, an invasive species that outcompetes native desert plants for space. Buffelgrass is highly flammable, and creates a continuous layer of grass that can fuel fast-moving wildfire.

Post-fire flooding

Following severe wildland fires, high-intensity summer thunderstorms can trigger extensive erosion and debris flows. Intense precipitation, even years after a severe fire, can also generate debris flows and other geomorphic changes; this occurred in the Sabino Canyon Recreation Area in Tucson, during a high-intensity precipitation episode in 2006, three years after the 84,750-acre Aspen fire in the Santa Catalina Mountains (Griffiths et al., 2009; Magirl et al., 2007). The event damaged structures and roads and affected infrastructure within Tucson's urban boundary. With the risk of fire along the foothills of the Tortolita mountains, post-fire flooding and debris flows into Dove Mountain is a possibility in the future.

Energy

Increased use of air conditioning (AC) from both higher 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). However, as temperatures warm in the wintertime, the need for energy for heating homes will likely decrease. Whether this will cancel out the increased energy use in the summer months is hard to determine (Cayan et al., 2013).

Furthermore, several studies (for example, de Munck et al., 2013; Ohashi et al., 2007) have shown that AC use in cities enhances the urban heat island effect (UHI), due to the release of waste heat from the systems themselves. The effect is more profound at night when heat emitted from AC systems can increase surface temperatures by up to 1.8° F (1° C) in the Phoenix Metro area (Salamanca et al., 2014). This creates a feedback loop, as higher nighttime temperatures increase AC use, heating the air even further. This is likely not an issue for The Highlands at Dove Mountain, as the community is located outside of the Tucson UHI, but it is an issue in other parts of the county.

The increased use of AC can also stress the electrical grid, increasing the risk for brownouts. In the Southwest U.S., "delivery of electricity may become more vulnerable to disruption due to climate-induced extreme heat and drought events as a result of: increased demand for home and commercial cooling; reduced thermal power plant efficiencies due to high temperatures; reduced transmission line, substation, and transformer capacities due to elevated temperatures; potential loss of hydropower production; threatened thermoelectric generation due to limited water supply; and the threat of wildfire to transmission infrastructure" (Tidwell et al., 2013). Additionally, 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 cooling (AC), and so on.

Real Estate/Demographics

There is growing evidence that climate change will affect human migration patterns as some regions become less livable and people move to more viable regions (McLeman and Smit, 2006). As in other areas of the world, climate change in Arizona will not be the sole factor influencing migration decisions, but in combination with other stressors such as social, cultural, and economic changes it can influence population movements and decision-making about migration.

There does not seem to be research available on how climate change might affect intra-state migration in Arizona (or evidence of this happening already), according to researchers at University of Arizona's College of Architecture, Planning, and Landscape Architecture.

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 lessen negative effects (Melillo et al., 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

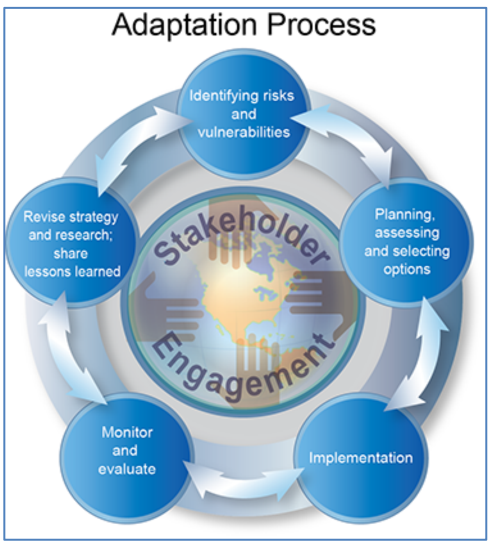

Figure 14: The Adaptation Process. Source http://nca2014.globalchange.gov/report/response-strategies/adaptation

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?

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).

The process of planning for climate change adaptation has already begun in many places. The federal government has required each federal agency to develop an adaptation policy (Executive Office of the President, 2013). Fifteen states and 176 cities have climate change adaptation plans.

Adaptation Strategies

In this section, we present a number of suggestions for possible adaptation strategies for The Highlands at Dove Mountain. As discussed above, decisions about which strategies will be most beneficial to and effective for any community should be made by the community. We present these strategies as options The Highlands can consider as part of its community planning processes.

Climate change adaptation strategies can be integrated into existing community plans, such as landscape or infrastructure management plans or can be stand-alone plans. In either case, revisiting the best-available data and evaluating the effectiveness of strategies on a regular basis is necessary to ensure the overall effectiveness of the plans. There are no specific guidelines for updating adaptation plans, but a good frame of reference is that FEMA requires counties and states to update their hazard mitigation plans every five years to ensure that data on hazards and vulnerabilities are kept up-to-date.

Golf Course Sustainability

The Highlands at Dove Mountain is already working to minimize use of water on its golf course, while also maintaining a high-quality golf course. The course managers use many of the best practices in sustainable golf course maintenance, such as:

- Ensuring the golf course drip irrigation system is modern and functioning properly to reduce leaks and save energy usage.
- Watering different zones of the golf courses separately and as needed, utilizing soil moisture monitoring instead of blanket timers for the entire courses.
- Keeping turf areas to a minimum.
- Evaluating the salt content of the reclaimed water used on the course to minimize damage to the turf.
- Evaluating the potential to use native or drought-resistant turf varieties where possible.

Some additional areas to consider:

- Regularly post information about water use and costs in the clubhouse to keep residents up-to-date about the links between water use, current water conservation efforts, and budget information.
- Promote the course as a premier desert landscaped course, as noted by Golf Arizona - http://www.golfarizona.com/courses/tucson/heritage-highlands.htm
- Replace any existing lakes with bunkers and native desert to reduce water use. Another option is to reduce the size of the lakes and turn them into more natural water features.
- Utilize compost from clubhouse and reuse grass trimmings for golf course turf.
- Capture rainfall and store it for later use (stormwater harvesting). This can be difficult to retrofit an existing course, but may be worth the long-term cost of buying less water. Here are two examples of courses doing this:
    - https://www.usga.org/articles/2016/10/alternative-water-supplies-a-win-for-golf-courses.html
    - http://www.g-a-l.info/golf-study.htm

Several golf courses in Arizona have utilized these strategies to increase their sustainability:

- Overview of current trends in golf course sustainability: https://urbanland.uli.org/sustainability/lack-water-hazard/
- Paradise Valley Country Club, Paradise, AZ: http://www.usga.org/articles/2015/07/sustainability-case-study--paradise-valley.html
- Ambient Golf Course, Scottsdale, AZ: http://www.usga.org/content/usga/home-page/course-care/water-resource-center/bmp-case-studies/2017/native-grasses-yield-water-savings.html

Emergency Preparedness

Fire Protection

The Firewise USA program teaches communities how to adapt to living with wildfire and encourages neighbors to work together and take action now to prevent losses. The Highlands is in the process of completing its application to become a Firewise community.

The Pima County Community Wildfire Protection Plan outlines fuel modification and treatment plans for different types of lands, but the overarching treatment is fuel reduction, including removing dead or dying debris, trimming down ladder fuels and fuels near power lines, and removing invasive species. It is recommended that larger modification projects be contracted through the fire department. Other recommendations, besides fuel modification, are listed on pages 107-111 of the plan, and include recommendations such as: meeting with representatives from TEP to identify locations of needed vegetative treatments, replacing and maintaining fencing adjacent to high-use and illegal off-road-vehicle use areas, acquiring a green-waste disposal site within a reasonable proximity to citizens and encourage its use for vegetative material removal on private lands.

Buffelgrass Reduction

A Pima County Ordinance requires the removal of buffelgrass. According to Tucson Clean and Beautiful, there are two ways to effectively kill buffelgrass: manually remove it or treat it with an herbicide – and monitor the area for at least 2-3 years to remove any regrowth.

- **Manual Removal:** Digging up buffelgrass clumps is a highly effective (though time consuming) way of killing buffelgrass. On larger clumps this is best done as a team, with one person digging around the roots and the other pulling the top of the grass (and perhaps a third person to bag or dispose of the grass!).
- After removal, buffelgrass should be placed in a plastic garbage bag and disposed of in the landfill. The bagging process is necessary to limit seed dispersal and to reduce potential fire hazard in urban areas.
- **Herbicide control**: When done correctly, using an herbicide with glyphosate as the active ingredient in accordance with label directions is an effective way to kill buffelgrass plants. However, the buffelgrass must be at least 50% green and actively growing for the herbicide to work effectively (spraying herbicide on dry grass or on barren ground is ineffective). Care must be taken to avoid spraying native or other desirable plants. There are drawbacks to this

method: the chemicals are expensive and the dead clump of buffelgrass will still present a fire hazard. Other chemicals may be available, but are typically more toxic and require further special handling. While homeowners can apply herbicide at their own home, applying herbicide on public lands requires trained/certified herbicide applicators and permission from the public land manager.

- **Mowing: NOT RECOMMENDED –** Use of weed-eaters and mowers is discouraged where buffelgrass is present, due to the risk of spreading seeds and ineffectiveness at actually addressing the roots of the plant. Mowing will only be effective at reducing the volume of material, and is only recommended if it will be followed by future manual removal or herbicide application as regrowth occurs.
- Other considered methods of removal (including by burning, animal grazing, salting, or with vinegar solutions) have not proven to be effective for controlling buffelgrass regrowth. Only methods that will remove the entire plant, or kill the green plant to its roots, combined with follow-up monitoring and light removal, have proven to be effective.
- **All mitigation methods: Ongoing monitoring required!** Regardless of the removal methodology used, buffelgrass plants will typically re-sprout from seed in the area where they were previously removed. For treatment to be effective, ongoing monitoring and additional small-scale removal will continue to be needed over a 2 to 5-year period, or longer, depending on site conditions and nearby seed sources.

Flood Insurance

The National Flood Insurance Program allows property owners in participating communities to buy insurance to protect against flood losses. Participating communities are required to establish management regulations in order to reduce future flood damages. This insurance is intended to furnish as an insurance alternative to disaster assistance and reduces the rising costs of repairing damage to buildings and their contents caused by flood.

Homeowners can determine whether their property lies in a flood-prone area by searching using an online tool developed by the Federal Emergency Management Agency. 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.

Additionally, most flood infrastructure is built with the 100-year historic flood as a reference. As storms are expected to become more intense, communities may consider reanalyzing existing drainage systems and washes to ensure that they can handle higher flooding.

Landscaping

Landscaping is an important part of the aesthetics of The Highlands. The community Common Areas Committee ensures that common areas are landscaped using low-water, desert-adapted vegetation and works exclusively with landscaping companies who are committed to maintaining these standards.

The Architecture and Landscaping Committee (ALC) ensures that private resident landscaping adheres to community standards. There are some opportunities through the ALC to encourage residents to move toward landscaping that embraces their Sonoran Desert surroundings.

- The ALC could include landscaping information in the welcome packet for new residents and make an introduction to desert landscaping part of the new resident orientation.
- The ALC could revise their approved plant list to include more desert-adapted species and design the list to highlight "strongly recommended" species that are low-water and desert-adapted. Resources for revising the plant list include:
    - Pima County Plant List; http://webcms.pima.gov/cms/One.aspx?portalId=169&pageId=52688
    - Arizona Municipal Water Users Association; https://www.amwua.org/plants/
    - Arizona-Sonora Desert Museum; https://www.desertmuseum.org/plantcare/
    - Tohono Chul; https://tohonochul.org/gardens-2/gardens/
- An annual xeriscape yard competition or showcase could incentivize the practice for residents.
- The ALC could host additional workshops or talks about desert landscaping. Some resources for speakers include:
    - UA Campus Arboretum; https://desertlandscaping.arizona.edu/
    - Watershed Management Group; https://watershedmg.org/
    - Pima County Master Gardeners; https://extension.arizona.edu/pima-master-gardeners
- Additional local resources for residents interested in learning more about desert landscaping:
    - Tucson Botanical Gardens; https://tucsonbotanical.org/community-resources/
    - Arizona Native Plant Society; http://www.aznps.com/nativegardening.php

Energy

Reducing household energy use is one way to both mitigate the causes of climate change (by reducing GHG emissions) and reduce household costs for energy.

- Consider installation of solar panels on HOA managed buildings or parking lots for both renewable energy and increasing available shade.
- Revisit the community's covenants, conditions, and restrictions (CC&Rs) and ensure they are in compliance with Arizona State Statute Article 3 chapter 4 section 33-439 which voids CC&Rs restricting installation of solar energy devices (https://www.azleg.gov/ars/33/00439.htm).
- Retrofit homes/buildings for energy efficiency
- A low-cost option is for individual homeowners to strategically plant shade trees to provide additional cooling for their homes and reduce their energy use and costs. Tucson Electric Power provides the following guidelines for their subsidized tree planting program:
    - Trees must be planted within 15 feet of the structure's west, east or south sides to provide shade during the summer months.
    - Trees also must be planted at least 10 feet from sewer lines, 5 feet from water lines and 3 feet from all other utility lines. Do not plant trees under any overhead utility

lines and maintain a safe distance from chimneys, power lines and other potential sources of combustion. Do not plant in a public right-of-way without a permit.

Social Resilience

The Building Resilient Neighborhoods (BRN) Work Group prepares Southern Arizona neighborhoods for extreme heat and other weather-related emergencies via community cohesion. BRN provides workshop education, materials, and best practices through community-led action and preparation. BRN is part of the Physicians for Social Responsibility-Arizona (PSR-AZ) Chapter based in Tucson. https://www.buildingresilientneighborhoods.org/

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