Flagstaff's Vulnerability to Climate Change

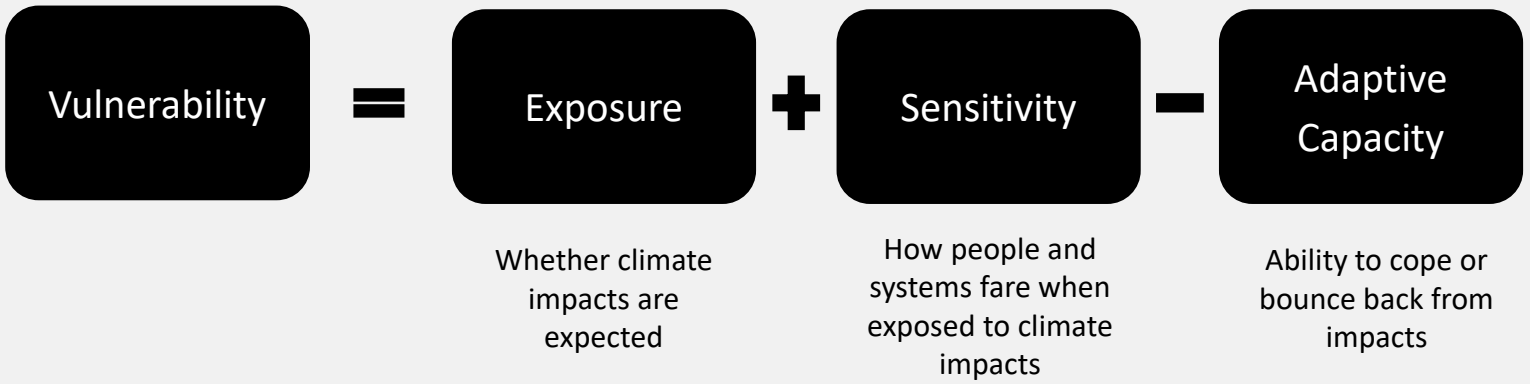
The vulnerability assessment in a nutshell

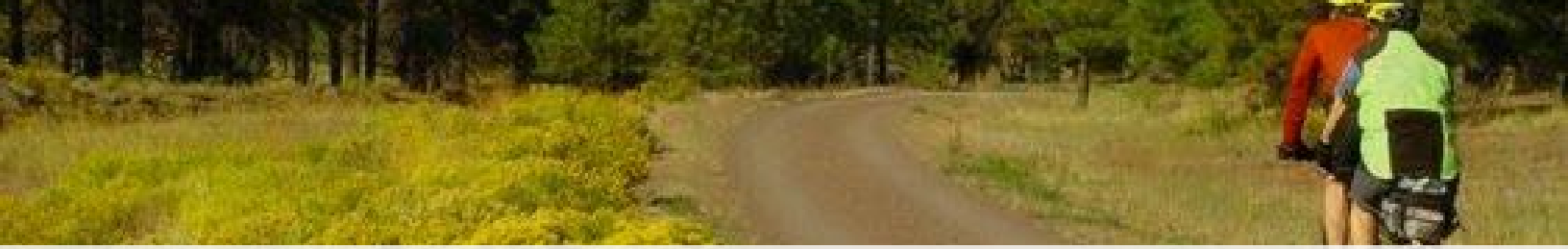
The climate change vulnerability assessment builds on the temperature and precipitation projections in the Climate Profile and identifies key climate-related risks to Flagstaff's communities, resources, and systems. This information will be used to decide which adaptation strategies to pursue to build Flagstaff's resilience.

Information in this assessment was drawn from peer-reviewed scientific literature; government, academic, and policy institute reports; and interviews with City of Flagstaff staff and local university researchers.

Sector	Low climate change vulnerability to/for:	Medium climate change vulnerability to/for:	High climate change vulnerability to/for:
Public health, safety, and emergency services	People with: • Allergies • Mental health issues • Other diseases	People sensitive to: • Poor air quality • Heat- and cold-related illnesses	
Land use, infrastructure, and cost of living	• Regional growth	• Utilities, buildings, and public transportation • Cost of living • Open space	
Forest health and wildfire		• Damage from post-fire flooding	Existing forests, from: • Wildfires • Forest pests and invasive species • Declining forest health
Water supply, quality, and infrastructure		• Water quality	• Long-term water supply • Water infrastructure
Tourism and recreation	• Summer recreation and tourism		• Winter recreation and tourism

What is Climate Change Vulnerability?





Public Health, Safety & Emergency Services

Vulnerability to Climate Change

A longer warm season and more intense wildfires may increase the risk of some diseases, mental illness, and respiratory health problems. Emergency response systems will need to be ready to respond to these risks.

In a changing climate, Flagstaff communities are likely to face:

MEDIUM VULNERABILITY

More periods of **poor air quality** due to larger, more frequent wildfires.

MEDIUM VULNERABILITY

More extreme heat days (>90°F) could increase the risk of **heat-related illness**.

LOW VULNERABILITY

Increased **exposure to allergens** is possible as spring grows warmer and more dry weather increases dust.

LOW-MEDIUM VULNERABILITY

More frequent extreme events could increase the **risk of mental health issues**.

LOW-MEDIUM VULNERABILITY

Increased **exposure to valley fever and West Nile virus** is possible as the warm season lengthens. Existing response resources may be adequate.

Poor air quality

Medium vulnerability *due to the need for more preventive measures and treatment of populations vulnerable to increased smoke exposure.*

In general, Flagstaff's air quality is rated moderate or better.[2] However, with larger, more frequent wildfires expected near Flagstaff, smoke and increased levels of particulate matter may significantly reduce air quality more often. Those with acute or chronic respiratory disease such as asthma, bronchitis, and pneumonia, especially those over 65 and under 4 years of age, are most at-risk from the adverse health effects of poor air quality.[7] Due to heightened smoke exposure, first responders and those who work outdoors are also at greater risk of smoke-related respiratory illness.

Communities At Risk

The very young and very old, outdoor workers, those with pre-existing illnesses or weak social ties, those living on the street, and low-income communities may be especially sensitive to climate change-related health impacts:

- The elderly, undocumented migrants, or people from families with mixed immigrant status are less likely to leave their homes to seek aid.
- Those experiencing homelessness, including forest dwellers, rely on public facilities and services for protection from extreme weather.
- Those with lower incomes may have to make difficult choices between paying for cooling or heating or meeting other basic needs, and may not have access to quality healthcare.
- In Flagstaff, low-income communities are disproportionately communities of color, specifically Hispanic (33%) and Native (29%) households.

Heat- and cold-related illness

Medium-high vulnerability *due to insufficient capacity and resources to prepare and protect vulnerable populations from the effects of extreme heat and cold.*

While extreme heat is not as common in Flagstaff as in southern Arizona, there are cases of heat-related illness and death. From 2005-2015, there were 18 deaths in Coconino County from exposure to excessive natural heat, and approximately 20 emergency department visits and hospital inpatient stays.[3] Data are not available on how many of these cases occurred in Flagstaff or were treated there. However, as the largest city in the county, Flagstaff's public health services may be called on more in the future to treat cases of extreme heat. By 2100, 30 to 80 days per year are expected to be above 90°F, compared to just 2 days per year between 1950 and 2017. This projected increase in days above 90°F could increase the risk of heat-related illness and death, especially for those who work outdoors, those who are experiencing homelessness, and households currently without air conditioning. Low-income households already struggling to afford basic needs could be particularly vulnerable to extreme heat without affordable options for air conditioning or refuge from extreme heat. The risk is further increased for emergency workers and first responders tasked with responding to summer wildfires.

Health concerns related to cold temperatures are likely to decline as winter temperatures warm. By 2100, as few as 100 days each year are expected to fall below freezing, compared to an average of 197 days per year from 1950 to 2017. Winter heating costs may decline and partially offset the expected increase in summer cooling costs. For those experiencing homelessness, fewer consecutive cold days may reduce the risk of cold-related injuries and death if necessary services are available for the remaining cold days. However, those experiencing homelessness (including forest dwellers) remain among the most vulnerable to very hot and very cold days, which are projected for up to half the year by 2100 (130 to 180 days above 90°F or below 32°F).

Mental health issues

Low-medium vulnerability *due to the need for increased capacity to address the needs of the small proportion of the population who may need more mental health care.*

Many people directly exposed to climate-related disasters experience serious mental health consequences, such as post-traumatic stress disorder (PTSD), depression, and general anxiety. While additional study is needed for the Flagstaff area, the possibility of more frequent and intense extreme events such as wildfire and post-wildfire flooding may increase the risk of mental illness. When extreme events cause loss of life, significant loss of resources, property or social support, or require relocation or other extensive changes to one's daily routine, the risk of mental illness increases.[8] Some studies also show a link between higher temperatures and increased rates of suicide.[8]

Allergies

Low vulnerability *because the public health system can handle a longer allergy season and the possibility of more people needing allergy care.*

A longer warm season, especially warming earlier in the spring, may lengthen the allergy season and increase exposure to allergens. The loss of vegetation from more frequent, large stand-replacing wildfires and more frequent, longer-lasting drought could also lead to more dust and increase exposure to airborne allergens.

INCREASED DEMANDS ON PUBLIC SAFETY AND EMERGENCY RESPONSE SYSTEMS

In Flagstaff, more intense wildfires, potential increases in post-wildfire flooding, and more days of extreme heat will increase demands on public safety resources, emergency services systems, and first responders and emergency workers. Permanent and seasonal population growth may further stress these systems: Flagstaff is expected to grow to 93,000 people (a 27% increase) and receive an increasing number of visitors per year by 2050. It may be challenging to maintain current response times without additional personnel.

Other diseases

Low-medium vulnerability *due to a public health system generally able to prevent and treat valley fever, West Nile virus, plague, Hantavirus, and Rocky Mountain Spotted Fever, even if the diseases become more prevalent.*

Valley fever occurs more often in Arizona than in most other parts of the U.S. West Nile virus is relatively uncommon, but does occur disproportionately in Arizona. Cases of both diseases are still primarily confined to southern Arizona.[i] While additional study is needed to understand the links between climate change and these diseases, there is some concern that valley fever and West Nile virus will become more prevalent in Flagstaff as temperatures warm. A longer warm season may increase the abundance of two mosquitoes known to carry West Nile virus, placing both humans and horses at greater risk of contracting the virus.[ii] Vulnerability to valley fever could increase due to limited capacity to treat the disease, limited knowledge about risk factors leading to exposure, or population growth among those more likely to contract the fever.[iii] For example, those over 65 are particularly susceptible to both valley fever and West Nile virus. With Flagstaff's retirement-age population expected to grow significantly in the coming decades, additional resources may be needed to prevent and treat these diseases.

Human cases of plague, Hantavirus Pulmonary Syndrome, and Rocky Mountain Spotted Fever are very rare in Coconino County but do occur.[iv] Research suggests that climate plays a role in both plague and Hantavirus Pulmonary Syndrome outbreaks, but it is unclear how the likelihood of outbreaks will change.[v] A climate link for Rocky Mountain Spotted Fever is difficult to establish.[vi]

Animals At Risk

West Nile virus and plague affect not only people, but also the animals they may rely upon or care about.

- **West Nile virus can cause a type of encephalitis in horses** that damages the central nervous system. Horses are revered among the Navajo Nation and Apache tribes and are important to the culture of the Hopi people as well. Ranchers and equestrians rely upon horses for income and enjoyment.
- Plague can affect any mammal, but **domestic cats experience especially high mortality from plague**.
- **Prairie dogs may be more susceptible to plague during dry years,** when food and water are more limited and their immune systems are weaker. Vaccination has proven effective in protecting these animals—which play a significant role in maintaining healthy grasslands—from plague.

---

i 69% (6,672) of valley fever cases and 4.2% of West Nile virus cases documented in the U.S. between 2005 and 2012 were in Arizona (see Reference 3). At that time, Arizona accounted for approximately 2% of the U.S. population. Between 2001 and 2014, 2.37-4.88 cases of West Nile virus per 100,000 people were documented in Graham County, compared to 0.11-0.52 cases per 100,000 people in Coconino County (see Reference 5).

ii See Reference 5. Morin & Comrie (2013) and Monaghan et al. (2018) also found that West Nile virus mosquito vectors are expected to increase in northern Arizona.

iii The soil-borne fungus that causes valley fever may be more prevalent when it is very hot during its early development (it is more resistant to heat than its competitors) or when it is dry either in previous seasons or during its growing season (the wind can carry dust containing the fungal spores to population centers). See Figure 15 in Reference 3 and Figure 4 in Reference 9.

iv From 2001-2014, there were 1-3 cases of Hantavirus, 1-5 cases of Rocky Mountain Spotted Fever, and 1 case of plague in Coconino County (see Reference 3).

v Research suggests human plague is more likely during warmer, wet years (see Reference 8) or following drought (see Reference 12). However, temperatures above 80.6 °F halt plague transmission (see Reference 3). While more intense monsoon rains and more drought are expected in Flagstaff, the number of days above 90 °F are also projected to increase (30 to 80 days per year by 2100). For Hantavirus, rodent populations are expected to increase where food becomes more abundant in warmer, wetter springs. Rodents carrying Hantavirus generally interact with people when they enter homes and buildings to escape hot, dry summers (see Reference 13) and very cold winters. While winters and springs are expected to warm in Flagstaff, so are summers.

vi Rocky Mountain Spotted Fever is most common in hot months (July-September). It is unclear if temperature influences the trend.

References

[1] W.-C. Chuang, A. Karner, N. Selover, D. M. Hondula, N. Chhetri, A. Middel, M. Roach and B. Dufour, "Arizona Extreme Weather, Climate and Health Profile Report," 2015.

[2] M. L. Sagna, S. Gupta and C. Torres, "Mortality and morbidity from exposure to excessive natural heat in Arizona, 2005-2015," Arizona Department of Health Services, Phoenix, 2017.

[3] M. Roach, H. E. Brown, M. Wilder, G. R. Smith, S. Chambers, I. E. Patten and Q. Rabby, "Assessment of Climate and Health Impacts on Vector-Borne Diseases and Valley Fever in Arizona," 2017.

[4] M. Roach, H. E. Brown, R. Clark, D. Hondula, J. Lega, N. Schweers and J. Tabor, "Projections of Climate Impacts on Vector-Borne Diseases and Valley Fever in Arizona," 2017.

[5] H. E. Brown, P. Ettestad, P. J. Reynolds, T. L. Brown, E. S. Hatton, J. L. Holmes, G. E. Glass, K. L. Gage and R. J. Eisen, "Climate predictors of the intra- and inter-annual distributions of plague cases in New Mexico based on 29 years of animal-based surveillance data," *Am. J. Trop. Med. Hyg.,* vol. 82, no. 1, pp. 95-102, 2010.

[6] H. E. Brown, A. C. Comrie, D. M. Drechsler, C. M. Barker, R. Basu, T. Brown, A. Gershunov, A. M. Kilpatrick, W. K. Reisen and D. M. Ruddell, ""Human Health." In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy," Island Press, Washington, DC, 2013.

[7] D. Dodgen, D. Donato, N. Kelly, A. La Greca, J. Morganstein, J. Reser, J. Ruzek, S. Schweitzer, M. M. Shimamoto, K. T. Tart and R. Ursano, "Ch. 8: Mental Health and Well-Being. In: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment," U.S. Global Change Research Program, Washington, DC, 2016.

[8] T. B. Ari, A. Gershunov, K. L. Gage, T. Snall, P. Ettestad, K. L. Kausrud and N. C. Stenseth, "Human plague in the USA: the importance of regional and local climate," *Biology Letter,* vol. 4, pp. 737-740, 2008.

[9] J. Shriber, K. C. Conlon, K. Benedict, O. Z. McCotter and J. E. Bell, "Assessment of vulnerability to Coccidioidomycosis in Arizona and California," *International Journal of Environmental Research and Public Health,* vol. 14, pp. 680-696, 2017.

[10] A. J. Monaghan, K. M. Sampson, D. F. Steinhoff, K. C. Ernst, K. L. Ebi, B. Jones and M. H. Hayden, "The potential impacts of 21st century climatic and population changes on human exposure to the virus vector mosquito Aedes aegypti," *Climatic Change,* vol. 146, pp. 487-500, 2018.

[11] C. W. Morin and A. C. Comrie, "Regional and seasonal response of a West Nile virus vector to climate change," *PNAS,* vol. 110, no. 39, pp. 15620-15625, 2013.

[12] D. A. Eads and J. L. Hoogland, "Precipitation, climate change, and parasitism of prairie dogs by fleas that transmit plague," *Journal of Parasitology,* vol. 103, no. 4, pp. 309-319, 2017.

[13] S. Carver, J. N. Mills, C. A. Parmenter, R. R. Parmenter, K. S. Richardson, R. L. Harris, R. J. Douglass, A. J. Kuenzi and A. D. Luis, "Toward a mechanistic understanding of environmentally forced zoonotic disease emergence: Sin Nombre Hantavirus," *BioScience,* vol. 65, no. 7, pp. 651-666, 2015.

Land Use, Infrastructure, and Cost of Living

Vulnerability to Climate Change

As our population continues to grow, we may have more people living in wildfire- and flood-prone areas despite the goals of our regional growth plan. Hotter temperatures may increase energy costs.

In a changing climate, Flagstaff communities are likely to face:

LOW-MEDIUM VULNERABILITY

Greater **population density** is planned away from wildfire- and flood-prone areas, with more city parks and open space to provide shade.

MEDIUM VULNERABILITY

Hotter temperatures may stress buildings, utilities, and roads.

MEDIUM VULNERABILITY

Hotter temperatures may increase energy costs and make summer cooling out of reach for many households.

MEDIUM-HIGH VULNERABILITY

Wildfires and hotter, drier conditions may make healthy open space more difficult to sustain.

CITY SPOTLIGHT

The **Flagstaff Regional Plan 2030: Place Matters** emphasizes reinvestment and compact, in-fill development to create high-density urban areas with mixed-used development. It also emphasizes limited, less dense suburban development at the city fringe. This approach has been shown to improve community resilience to a variety of stressors.

The Plan's water, energy and natural area conservation, increased open space, and emphasis on multimodal transportation also increase the city's climate resilience. Annual reports indicate nearly all metrics are holding steady or improving.

Regional Growth

Low-medium vulnerability *due to a strong regional growth plan that generally directs development away from wildfire- and flood-prone areas.*

Flagstaff's population is expected to continue to grow and age. Approximately 73,000 people live in Flagstaff today.[4] By 2030, a 12 percent increase (to 82,000) is projected and by 2050, the population may reach 93,000.[2] Of this, the proportion of those over 65 is expected to increase as Baby Boomers retire and move to the area; currently about 6 percent (4,233) of the population is over 65.

While more extreme heat in the Southwest's warmer cities could encourage migration to relatively cooler cities like Flagstaff either permanently or seasonally, it is too soon to tell if climate-driven migration will be a significant factor in Flagstaff's future growth.[5-9] Most people in the United States move for better jobs, but they also consider whether close friends and family are nearby, cultural preferences, and environmental factors.[7,9-13] In cases where environmental factors play a larger role, those with college educations, those of moderate income, retirees, and those who work in tourism are most likely to migrate for a comfortable climate.[6-9,15] Conversely, those most vulnerable to climate extremes are the least likely to move because they often lack the needed economic and social resources.[i]

Nonetheless, Flagstaff is taking steps to manage growth to reduce vulnerability to climate change and other hazards. Most of Flagstaff's current population lives near I-40, especially on the northwest side and where I-40 and I-17 meet.[ii] Future growth plans concentrate development in these existing road corridors and reduce exposure to the wildland-urban interface where wildfire risk is higher.[iii] However, additional low-density private development is planned at the city fringes and could increase exposure to wildfire and post-fire flooding. Despite plans to increase public services, outlying communities would remain less connected to the urban core where most resources are located. In rural areas, it may take longer for emergency services to reach residents and for power, communications, or other utilities to be restored after a wildfire, flood, or other emergency.[3]

Infrastructure

Medium vulnerability *due to hotter temperatures, wildfire, flooding, and the need to more consistently protect infrastructure or adjust systems to compensate for risks.*

Hotter temperatures and expected increases in the size and frequency of wildfires and floods could strain City resources by damaging or reducing the usable life of Flagstaff's utilities, buildings, and public transit, airport, and other transportation infrastructure.[3] Many of the city's utilities are over 50 years old and in need of repair, refurbishment, or replacement, which, if completed, could make them more resilient to future climate impacts.[18] Buildings may require more energy to cool and energy costs may rise due to increased energy demand.[3] The overall projection for a more moderate climate with fewer freeze-thaw cycles may reduce the need for some types of pavement maintenance.[iv]

Public transit is an increasingly popular mode of travel in the Flagstaff area: ridership has increased from nearly 200,000 rides in 2001 to 1.96 million rides in 2016, and an estimated 59 percent of the population lives within three-quarters of a mile of a transit stop.[18,19] For those with respiratory or cardiac conditions, those who are elderly, and those who walk or cannot drive as a primary form of transportation, extreme heat or poor air quality due to wildfire smoke may increase demand for public transit services, including Para-transit. This increased demand can mostly be met by adjusting service levels.[3]

Cost of Living

Medium vulnerability *due to the anticipated need for air conditioning, which will be difficult for many communities to afford without rebates or other support programs.*

With a cost of housing that is 37 percent higher than the national average, owning a home is out of reach for many Flagstaff residents; in 2016, about half the population rented their home.[v] Many also face a housing cost burden: of the 40 percent of low- to moderate-income households in Flagstaff, many pay more than 30 percent of their income on

---

[i] Poor, disconnected, and disempowered people are highly vulnerable to environmental extremes (see References 12, 16, and 17).

[ii] See p. 21 in Reference 18 for a 2010 map of population and housing density.

[iii] By 2015, multi-modal studies were finished or underway for Kachina Village, Doney Park, & Bellemont (see Reference 2).

[iv] While days well above 100°F are expected only rarely in Flagstaff's future, temperatures above 115°F have been shown to weaken pavement or reduce the number of flights that can take off from the airport.

[v] The median home sold for about $300,000 from 2014 to 2016. In 2016, 24.2% of Flagstaff lived in poverty. See References 18 & 19.

housing and struggle to afford other basic needs such as home heating, transportation, and food.[vi] Affordable housing is being generated very slowly: just 7 of the 1,324 units built from 2014 to 2016 were affordable.[19] These are located in the Sunnyside neighborhood, most of which is outside the 500-year floodplain. However, other low- and moderate-income neighborhoods are located in wildfire- and flood-prone areas (Southside, Plaza Vieja, Pine Knoll, Mobile Haven, Woodland Hills, Kit Carson).

Despite City efforts, housing costs are expected to continue to rise in Flagstaff as the population grows, Baby Boomers retire, and purchases of second homes increase.[vii] The City's goal is to disperse future affordable housing units throughout the community to create mixed-income neighborhoods. It is likely that the City's new affordable housing will be built on smaller infill sites throughout the city, and it is unknown where private developers may build affordable units. Therefore, exposure to wildfire and flooding is difficult to anticipate.

The region's growth and hotter summers will also increase demand for energy, especially air conditioning, which may lead to higher residential energy costs.[3] Winter heating costs may or may not decline enough to compensate for increased summer demand. The possibility of higher energy costs, paired with projected increases in housing costs, could further stress households who already face a housing cost burden. The City's current rebates and other incentives for renewable energy and energy conservation could address the risk of rising household energy costs.[3]

Open Space

Medium-high vulnerability *due to most open space being prone to wildfire and the lack of resilience of some plants and trees to anticipated future climate conditions.*

Open space helps reduce the urban heat island effect and sequester carbon; if trees have been properly thinned, the presence of open space will not substantially increase wildfire risk. Open space, and more broadly, conservation of natural areas such as slopes, forests, and floodplains are priorities in Flagstaff's regional plan.[2,18] Between 2002 and 2016, the City of Flagstaff acquired 2,769 acres of open space, including the 478-acre Picture Canyon.[18-20] In total, 2,990 acres in Flagstaff are zoned as open space, and there are 766 acres of parks.[19] As open space is established and maintained, using trees and plants well-suited to the warmer temperatures and more intense monsoons expected in Flagstaff could protect investments in open space.

[vi] In 2011, the median household income was $42,511, and about 20% of those making less than $20,000 and 15% of those making $20,000-34,999 faced a housing cost burden (see Reference 18). Median 2016 earnings were $18,760; per capita earnings were $25,179 (see Reference 19).

[vii] There are 33,816 total housing units in the broader Flagstaff metropolitan area (129+ units are affordable). An additional 6,000 units are anticipated to be needed by 2030. See Reference 18.

References

[1] ESRI, 2018. [Online]. Available: www.arcgis.com/apps/MapJournal/index.html?appid=020efc7d700b4c7b81a6eb3b860311a1#. [Accessed 22 February 2018].

[2] Coconino County, City of Flagstaff, Town of Fredonia, City of Page, Town of Tusayan and City of Williams, "Coconino County Multi-Jurisdictional Hazard Mitigation Plan," Coconino County, 2015.

[3] City of Flagstaff, "City of Flagstaff Resiliency and Preparedness Study," Flagstaff, AZ, 2012.

[4] Arizona Office of Economic Opportunity, "July 1, 2017 Population estimates for Arizona's counties, incorporated areas, and unincorporated balance of counties," 2017. [Online]. Available: https://population.az.gov/sites/default/files/documents/files/pop-estimates2017-04pla.pdf. [Accessed 23 February 2018].

[5] R. McLeman and B. Smit, "Migration as an adaptation to climate change," *Climatic Change,* vol. 76, pp. 31-53, 2006.

[6] R. A. McLeman and L. M. Hunter, "Migration in the context of vulnerability and adaptation to climate change: insights from analogues," *Wiley Interdisciplinary Reviews: Climate Change,* vol. 1, no. 3, pp. 450-461, 2010.

[7] D. L. Poston, L. Zhang, D. J. Gotcher and Y. Gu, "The effect of climate on migration: United States, 1995-2000," *Social Science Research,* vol. 38, no. 3, pp. 743-753, 2009.

[8] Q. Fan, H. A. Klaiber and K. Fisher-Vanden, "Climate Change Impacts on U.S. Migration and Household Location Choice," 2012. [Online]. Available: ageconsearch.umn.edu/bitstream/124588/2/Fan_Klaiber_Fisher-Vanden_AAEA.pdf. [Accessed 2/23/2018].

[9] A. Saperstein, "Climate Change, Migration, and the Puget Sound Region: What We Know and How We Could Learn More," 2015. [Online]. Available: https://cig.uw.edu/wp-content/uploads/sites/2/2015/10/Climate-Migration-Saperstein-Final-Aug-3-2015.pdf. [Accessed 23 February 2018].

[10] S. B. Adamo and A. M. de Sherbinin, "Migration and Environmental Change in North America (USA and Canada)," in *People on the Move in a Changing Climate: The Regional Impact of Environmental Change on Migration*, Dordrecht. Netherlands, Springer Science & Business Media , 2014, pp. 135-153.

[11] E. Piguet, A. Pecoud and P. de Guchteneire, Migration and Climate Change, Paris, France and United Kingdom: United Nations Educational, Scientific and Cultural Organization and Cambridge University Press, 2011.

[12] R. Black, N. W. Arnell, W. N. Adger, D. Thomas and A. Geddes, "Migration, immobility and displacement outcomes following extreme events," *Environmental Science & Policy,* vol. 27, no. Supplement 1, pp. S32-S43, 2013.

[13] A. M. Findlay, "Migrant destinations in an era of environmental change," *Global Environmental Change,* pp. S50-58, 2011.

[14] L. M. Hunter, S. Murray and F. Riosmena, "Rainfall patterns and U.S. migration from rural Mexico," *International Migration Review,* vol. 47, no. 4, pp. 874-909, 2013.

[15] Y. Chen, E. G. Irwin and C. Jayaprakash, "Dynamic modeling of environmental amenity-driven migration with ecological feedbacks," *Ecological Economics,* vol. 68, no. 10, pp. 2498-2510, 2009.

[16] T. Faist and J. Schade, "The climate-migration nexus: A reorientation," in *Disentangling Migration and Climate Change: Methodologies, Political Discourses and Human Rights*, New York, Springer Science+Business Media Dordrecht, 2013, pp. 3-25.

[17] R. Zetter and J. Morrissey, "The environment-mobility nexus: Reconceptualizing the links between environmental stress, im(mobility), and power," *The Oxford Handbook of Refugee and Forced Migration Studies,* p. 342, 2014.

[18] City of Flagstaff, "Flagstaff Regional Plan 2030: Place Matters," City of Flagstaff, Flagstaff, AZ, 2014.

[19] City of Flagstaff, "Flagstaff Regional Plan 2030: 2016 Annual Report," City of Flagstaff, Flagstaff, AZ, 2017.

[20] City of Flagstaff, "Picture Canyon Natural and Cultural Preserve," 2018. [Online]. Available: http://www.flagstaff.az.gov/2881/Picture-Canyon. [Accessed 23 February 2018].

[21] A. L. Westerling, H. G. Hidalgo, D. R. Cayan and T. W. Swetnam, "Warming and earlier spring increases western U.S. forest wildfire activity," *Science,* vol. 313, pp. 940-943, 18 August 2016.

[22] J. T. Abatzoglou and A. P. Williams, "Impact of anthropogenic climate change on wildfire across western U.S. forests," *PNAS,* vol. 113, no. 42, pp. 11770-11775, 18 October 2016.

[23] A. P. Williams, C. D. Allen, C. L. Millar, T. W. Swetnam, J. Michaelsen, C. J. Still and S. W. Leavitt, "Forest responses to increasing aridity and warmth in the southwestern United States," *PNAS,* vol. 107, no. 50, pp. 21289-21294, 14 December 2010.

[24] J. S. Littell, D. L. Peterson, K. L. Riley, Y. Liu and C. H. Luce, "A review of the relationships between drought and forest fire in the United States," *Global Change Biology,* vol. 22, pp. 2353-2369, 2016.

Forest Health & Wildfire

Vulnerability to Climate Change

A longer warm season and drier climate are likely to reduce overall forest health, lead to more damaging and hazardous wildfires and floods, and enable worsening pine beetle infestations. Forest management and emergency response systems will need to be ready to respond to these growing threats.

In a changing climate, Flagstaff communities are likely to face:

HIGH VULNERABILITY

Larger, more frequent stand-replacing **wildfires.**

MEDIUM-HIGH VULNERABILITY

Larger, more frequent **flooding** after wildfires. More floods in general.

HIGH VULNERABILITY

More **beetle infestations and invasive species** due to warmer, drier conditions.

VERY HIGH VULNERABILITY

Overall **declines in forest health and widespread forest loss** due to wildfires, drought, pests, and invasive species.

Wildfires

High vulnerability *due to more frequent, larger stand-replacing fires—despite active, coordinated efforts to prevent and prepare for local wildfire impacts.*

As one of the most fire-adapted tree species, Ponderosa pine rely upon frequent, lower-heat fires to maintain an open forest structure. Ponderosa pine forests near Flagstaff historically burned every 2 to 24 years and had an average tree density much lower than today's density: 22.8 trees per acre in 1876 compared to 1,256 trees per acre in 1992, the most recent year with ample data available.[22,23]

Larger, hotter fires have become more common across the Southwest since the 1980s,[10] driven by the kind of prolonged drought and large insect outbreaks that Flagstaff is expected to see more of in the future. The second-largest wildfire in

Preparing for More Wildfires

- In 2008, the City adopted a **comprehensive Wildland-Urban Interface Code** to hold property owners and developers to standards that reduce wildfire risks.
- The **Greater Flagstaff Area Community Wildfire Protection Plan** and local **FireWise** program are educating communities about how they can prevent wildfires and protect their homes and community.
- Through the **Greater Flagstaff Forest Partnership**, over 40,000 acres have been thinned since 2004.
- The **Flagstaff Water Protection Project** (FWPP) focuses thinning and prescribed fire on two high-risk areas—Dry Lake Hills and Mormon Mountain—where wildfire and post-fire flooding would cause millions in damage and make Upper Lake Mary Reservoir temporarily unusable.
- Similar to FWPP, the **Four Forest Restoration Initiative** restores fire-adapted Ponderosa pine ecosystems through fuels reduction, habitat improvements, reforestation, noxious weed removal, trail and road upkeep, and watershed maintenance.

Arizona state history—the Rodeo-Chediski Fire of 2002—occurred during the state's worst recorded drought and burned over 468,638 acres across several counties including Coconino County.[2,11] In 2010, the Schultz Fire burned over 15,000 acres northeast of Flagstaff and cost an estimated $193 to $207 million to respond, mitigate, and recover from the fire.[i] Additional wildfires have also burned in the Ponderosa pine forests surrounding the city in more recent years (Figure 1).

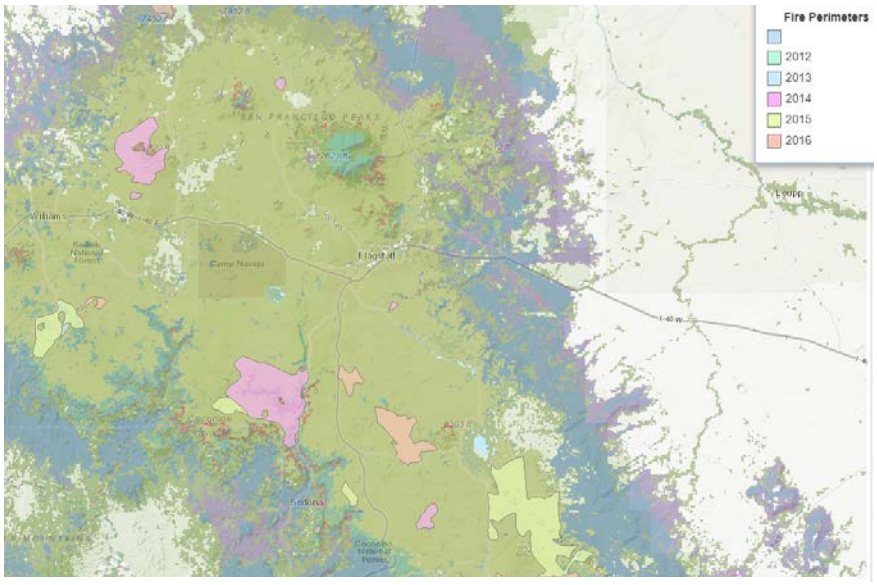


Figure 1. Recent fires near Flagstaff (USFS NDM). The large areas shaded in green represent Ponderosa pine forests.

The much higher densities in today's forests are due largely to decades of fire suppression, livestock grazing, and logging.[20,21] Combined with a growing population and climate change, a longer fire season with more frequent large, stand-replacing wildfires is expected in the Flagstaff area.[4,5,12,13] At the same time, trees will become increasingly stressed by warmer, drier conditions and insect outbreaks, and more vulnerable to damage.[4,5,12,13] The total area burned near Flagstaff may increase as much as 382 percent compared to the second half of the 20th century with just a 1.8°F increase in average temperature.[ii] The average temperature is expected to increase approximately 4°F by 2050 under a lower-emissions scenario, suggesting this estimate of area burned may be conservative.

Most fires are human-caused (campfires, burning trash, equipment sparks, etc.), while some others are caused by lightning strikes.[15,16] As Flagstaff's population grows nearly 30 percent by 2050, there could be more incidents of human-caused fires. At the same time, vulnerability is expected to increase, particularly among those with pre-existing respiratory conditions, newcomers with little knowledge about wildfire safety, first responders, and those living near where the city and forest meet. An estimated 30 percent of Flagstaff's buildings (residential, commercial, and industrial) are located in areas with a medium wildfire hazard and 8 percent of buildings are in areas with high wildfire hazard; a wildfire in these areas would cause millions of dollars of damage.[iii]

[i] Wildfire response and mitigation cost an estimated $60 million, most of which was covered by federal funds. An additional $133 to $147 million was needed to address post-fire flooding impacts, including habitat destruction and loss of life. See Reference 30.

[ii] Compared to 1950-2003 (see Reference 14). In addition, Spracklen et al. (2009) (see Reference 6) project a 43 percent increase in area burned by the 2050s (2046-2055 compared to 1980-2004) with a three-fold increase in carbon dioxide.

[iii] Wildfire damage to these buildings has been estimated at $298 million (high-hazard) and $21 million (medium-hazard). Estimates assume a 20% loss per building for high-hazard areas, and a 5% loss per building for medium-hazard areas (see Reference 1).

Post-fire flooding

Medium-high vulnerability *due to more frequent, large stand-replacing wildfires and the difficulty of protecting homes and structures despite robust response protocols.*

Flooding in Flagstaff is linked to heavy monsoon rains in summer and early autumn, and long periods of low-intensity rain in the winter, especially following snowfall.[11] Many of Flagstaff's low- and moderate-income neighborhoods are partially or wholly within the 500-year floodplain and flood more often than other areas of the city.[iv]

Wildfires also lead to substantial post-fire flooding because they dry out soil, reduce water absorption, and burn the trees and plants that hold soil in place. Even a normal rainstorm following a wildfire can wash large quantities of soil and water from fire-affected slopes and into waterways.[7] Most post-fire flooding occurs in communities living near the forest edge. These floods may recur for several years while vegetation regrows on burned slopes. Flooding triggered by the 2010 Schultz Fire cost an $133-147 million and affected Doney Park, Timberline-Fernwood, and other communities up to four miles from the fire's location.[1,30] Flooding continued for four years after the fire, causing additional damage to property, utilities, and roads.[1,30]

The projection for more frequent wildfires suggests flooding after wildfires will also become more frequent. An estimated 8-10 percent of Flagstaff's overall population and 6-10 percent of the over-65 population lived in medium- and high-hazard flooding areas in 2009, the most recent year for which this data is available.[1] Additionally, damage to residential, commercial, and industrial buildings in medium- and high-hazard areas would cost millions of dollars.[v] A wildfire and post-fire flooding in Dry Lake Hills or Mormon Mountain could cost Flagstaff $573 million to $1.2 billion.[29]

Local Flood Resilience

To prepare for floods, the **City offers residents and business owners discounts** for detention basins, rainwater harvesting systems, and facilities that use natural features to manage rain and floodwaters. The City also invests in drainage and flood control projects such as the **Rio De Flag Flood Control Project**, **Fanning Drive and Steves Boulevard Drainage Improvement**, and **Five Points Drainage Improvement**. During floods, emergency responders from across the city work together to evacuate and temporarily house affected residents, push back the floodwaters, and begin the long recovery process.

Forest pests and invasive species

High vulnerability *due to the widespread need for forest health treatments to increase the resilience of Ponderosa pine forests to forest pests and invasive species.*

The Ponderosa pine forests surrounding Flagstaff are most susceptible to dwarf mistletoe, western pine beetle, and mountain pine beetle (Figure 2). Dwarf mistletoe and both beetles reduce tree growth, increase tree mortality, and make trees more sensitive to disturbance of any kind; the beetles also dry out trees.[8] Dwarf mistletoe also predisposes trees to drought, which in some cases makes trees more susceptible to beetle attack.[25]

[iv] This includes the Southside, Sunnyside, Plaza Vieja, Pine Knoll, and Mobile Haven neighborhoods, along with the Woodland Hills and Kit Carson trailer parks.

[v] Losses have been estimated at $120 million (high hazard) and $25 million (medium hazard). These estimates are based on FEMA's 2001 loss estimation tables. They assume a 20% loss per building for high-hazard areas, and a 5% loss per building for medium-hazard areas (see Reference 1). Flooding-related costs from the Schultz Fire were $133-147 million.

Figure 2. Mountain pine beetle (left) and dwarf mistletoe, orange in color (right). Sources: Government of Alberta and Mike Simpson.

Dwarf mistletoe is the most common pathogen across the Southwest and currently affects more than one-third of Ponderosa pine forests in the region.[8]

From 2000 to 2016, bark beetles infested at least four percent and in some areas more than 50 percent of forests near Flagstaff.[19] There is significant variability from year to year:

- **Western pine beetle** affected approximately 10,000 acres in 2012 and 20,000 acres in 2013, but just 643 acres in 2014.[17] Most western pine beetle outbreaks were in southwestern white pine rather than Ponderosa pine.[8] This may be due to thinning of Ponderosa pine forests, which supports tree health and makes trees more resilient to beetle attack.
- **Mountain pine beetle** infested approximately 500 acres each year in 2013 and 2014, compared to just 10 acres in 2016.[18]

Outbreaks of both western pine and mountain pine beetle near Flagstaff are expected to increase as more beetles survive the cold season[4] and warmer, drier conditions weaken trees. Dwarf mistletoe may grow less vigorously in a drier future, but infected trees, especially those in dense stands, are expected to be at increased risk of drought, insect infestation, and mortality.[24,25] Ponderosa pine may lose its relative ability to fend off beetle attack, increasing the vulnerability of these forests to beetle outbreaks, drought, and wildfire.

Overall forest health

Very high vulnerability *due to the projected inability of Ponderosa and pinyon pine forests to recover from stand-replacing wildfire, widespread insect outbreaks, and severe drought as temperatures increase.*

The Ponderosa pine forest around Flagstaff is the largest continuous forest of its kind in the world. A legacy of fire suppression, grazing, and logging has left forests far denser than their natural state, which can reduce individual tree vigor and increase susceptibility to insect outbreaks, drought, and wildfire. Pinyon pine forests near Flagstaff experienced a significant die-off when conditions remained very dry for several years around the turn of the 21st century.

Forests of the southwest U.S. may give way to grassland and shrubland landscapes as the climate grows hotter and drier and the characteristic Ponderosa and pinyon pine forests struggle to re-establish as larger, stand-replacing wildfires grow more frequent and leave fewer parent trees to seed the next generation.[26-28] As early as 2075 in a high-emissions future, Ponderosa pine forests may begin to decline or shift to the east where climate may be more suitable.[9] By 2100, widespread losses of pinyon and Ponderosa pine forests are projected, with overall growth of pinyon and Ponderosa pine forests declining 40-50 percent in this timeframe.[12,26-28]

The elk, deer, and antelope hunted by the Hopi people may decline with the forests or persist if emerging grasslands offer a good source of food. Other insects, animals, and plant life native to the pinyon and Ponderosa pine forests that the Hopi people, Navajo Nation, and other tribes rely upon for sustenance, ceremonies, or other uses are likely to decline along with those forests, which may disrupt traditional practices among these tribes.

References

[1] Coconino County, City of Flagstaff, Town of Fredonia, City of Page, Town of Tusayan and City of Williams, "Coconino County Multi-Jurisdictional Hazard Mitigation Plan," Coconino County, 2015.

[2] D. Bachelet, J. M. Lenihan and R. P. Neilson, "Wildfires and global climate change: The importance of climate change for future wildfire scenarios in the western United States," 2007.

[3] M. D. Hurteau, J. B. Bradford, P. Z. Fule, A. H. Taylor and K. L. Martin, "Climate change, fire management, and ecological services in the southwestern U.S.," *Forest Ecology and Management,* vol. 327, pp. 280-289, 2014.

[4] B. J. Bentz, J. Regniere, C. J. Fettig, E. M. Hansen, J. L. Hayes, J. A. Hicke, R. G. Kelsey, J. F. Negron and S. J. Seybold, "Climate change and bark beetles of the western United States and Canada: Direct and indirect effects," *BioScience,* vol. 60, no. 8, pp. 602-613, September 2010.

[5] J. S. Littell, D. L. Peterson, K. L. Riley, Y. Liu and C. H. Luce, "A review of the relationships between drought and forest fire in the United States," *Global Change Biology,* vol. 22, pp. 2353-2369, 2016.

[6] D. V. Spracklen, L. J. Mickley, J. A. Logan, R. C. Hudman, R. Yevich, M. D. Flannigan and A. L. Westerling, "Impacts of climate change from 2000 to 2050 on wildfire activity and carbonaceous aerosol concentrations in the western United States," *Journal of Geophysical Research,* vol. 114, no. D20301, pp. 1-17, 2009.

[7] G. Garfin, S. LeRoy, D. Martin, M. Hammersley, A. Youberg and R. Quay, "Managing for future risks of fire, extreme precipitation, and post-fire flooding," Institute of the Environment, Tucson, AZ, 2016.

[8] U.S. Forest Service, "Forest insect and disease conditions in the Southwestern region, 2015," U.S. Forest Service Southwest Region, 2016.

[9] R. S. Thompson, S. W. Hostetler, P. J. Bartlein and K. H. Anderson, "A strategy for assessing potential future changes in climate, hydrology, and vegetation in the western United States," United States Government Printing Office, Washington, 1998.

[10] A. L. Westerling, H. G. Hidalgo, D. R. Cayan and T. W. Swetnam, "Warming and earlier spring increases western U.S. forest wildfire activity," *Science,* vol. 313, pp. 940-943, 18 August 2016.

[11] ESRI, 2018. [Online]. Available: https://www.arcgis.com/apps/MapJournal/index.html?appid=020efc7d700b4c7b81a6eb3b860311a1#. [Accessed 22 February 2018].

[12] A. P. Williams, C. D. Allen, C. L. Millar, T. W. Swetnam, J. Michaelsen, C. J. Still and S. W. Leavitt, "Forest responses to increasing aridity and warmth in the southwestern United States," *PNAS,* vol. 107, no. 50, pp. 21289-21294, 14 December 2010.

[13] J. T. Abatzoglou and A. P. Williams, "Impact of anthropogenic climate change on wildfire across western U.S. forests," *PNAS,* vol. 113, no. 42, pp. 11770-11775, 18 October 2016.

[14] National Research Council, "Climate stabilization targets: Emissions, concentrations, and impacts over decades to millenia," The National Academies Press, Washington, DC, 2011.

[15] C. Joyce, "What's the leading cause of wildfires in the U.S.? Humans," 27 February 2017. [Online]. Available: https://www.npr.org/sections/thetwo-way/2017/02/27/517100594/whats-the-leading-cause-of-wildfires-in-the-u-s-humans. [Accessed 22 February 2018].

[16] W. Cornwall, "Who is starting all those wildfires? We are," 12 September 2017. [Online]. Available: http://www.sciencemag.org/news/2017/09/who-starting-all-those-wildfires-we-are. [Accessed 22 February 2018].

[17] U.S. Forest Service, "Trend for Western Pine Beetle: Coconino County," 2018. [Online]. Available: https://foresthealth.fs.usda.gov/portal/Flex/FPC. [Accessed 22 February 2018].

[18] U.S. Forest Service, "Trend for Mountain Pine Beetle Summary: Coconino County," 2018. [Online]. Available: https://foresthealth.fs.usda.gov/portal/Flex/FPC. [Accessed 22 February 2018].

[19] U.S. Forest Service, "GIS & Spatial Analysis (2000-2016 Areas with Tree Mortality from Bark Beetles in the Western United States)," 9 November 2017. [Online]. Available: https://www.fs.fed.us/foresthealth/technology/pdfs/MpbWestbb_Summary.pdf. [Accessed 22 February 2018].

[20] W. W. Covington and M. M. Moore, "Post settlement changes in natural fire regimes and forest structure: ecological restoration of old-growth Ponderosa pine forests," *Journal of Sustainable Forestry,* vol. 2, pp. 153-181, 1994.

[21] P. Z. Fule, W. W. Covington and M. M. Moore, "Determining reference conditions for ecosystem management of southwestern Ponderosa pine forests," *Ecological Applications,* vol. 7, no. 3, pp. 895-908, 1997.

[22] R. T. Reynolds, A. J. Sanchez Meodor, J. A. Youtz, T. Nicolet, M. S. Matonis, P. L. Jackson, D. G. DeLorenzo and A. D. Graves, "Restoring composition and structure in southwestern frequent-fire forests: A science-based framework for improving ecosystem resiliency," U.S. Forest Service, Rocky Mountain Research Station, 2013.

[23] W. W. Covington, P. Z. Fule, M. M. Moore, S. C. Hart, T. E. Kolb, J. N. Mast, S. S. Sackett and M. R. Wagner, "Restoring ecosystem health in Ponderosa pine forests of the Southwest," *Journal of Forestry,* vol. 95, no. 4, pp. 23-29, 1997.

[24] C. P. Bickford, T. E. Kolb and B. W. Geils, "Host physiological condition regulates parasitic plan performance: Arceuthobium vaginatum subsp. cryptopodum on Pinus ponderosa," *Oecologia,* vol. 146, pp. 179-189, 2005.

[25] T. E. Kolb, C. J. Fettig, M. P. Ayres, B. J. Bentz, J. A. Hicke, R. Mathiasen, J. E. Stewart and A. S. Weed, "Observed and anticipted impacts of drought on forest insects and diseases in the United States," *Forest Ecology and Management,* vol. 380, pp. 321-334, 2016.

[26] X. Jiang, S. A. Rauscher, T. D. Ringler, D. M. Lawrence, A. P. Williams, C. D. Allen, A. L. Steiner, D. M. Cai and N. G. McDowell, "Projected future changes in vegetation in western North America in the Twenty-First Century," *Journal of Climate,* vol. 26, pp. 3671-3687, 2013.

[27] A. P. Williams, C. D. Allen, A. K. Macalady, D. Griffin, C. A. Woodhouse, D. M. Meko, T. W. Swetnam, S. A. Rauscher, R. Seager, H. D. Grissino-Mayer, J. S. Dean, E. R. Cook, C. Gangodagamage, M. Cai and N. G. McDowell, "Temperature as a potent driver of regional forest drought stress and tree mortality," *Nature Climate Change,* p. 6, 2012.

[28] N. G. McDowell, A. P. Williams, C. Xu, W. T. Pockman, L. T. Dickman, S. Sevanto, R. Pangle, J. Limousin, J. Plaut, D. S. Mackay, J. Ogee, J. C. Domec, C. D. Allen, R. A. Fisher, X. Jiang, J. D. Muss, D. D. Breshears, S. A. Rauscher and C. Koven, "Multi-scale predictions of massive conifer mortality due to chronic temperature rise," *Nature Climate Change,* p. 6, 2015.

[29] Arizona Rural Policy Institute, "Flagstaff Watershed Protection Project: Cost Avoidance Study," Arizona Rural Policy Institute, 2014.

[30] T. Combrink, C. Cothran, W. Fox, J. Peterson and G. Snider, "A full cost accounting of the 2010 Schultz Fire," Ecological Restoration Institute, Northern Arizona University, Flagstaff, 2013.

Water Supply, Quality, & Infrastructure

Vulnerability to Climate Change

Our water comes from forests at high risk of significant wildfire damage. As our population grows, tourism increases, and the climate changes, our water resources will be stressed despite progress in water conservation. Our community will need to be ready.

In a changing climate, Flagstaff communities are likely to face:

HIGH VULNERABILITY

Reduced water availability and increased demand could cause water shortfalls.

MEDIUM-HIGH VULNERABILITY

More **wildfire, drought, and flooding** are likely to impair water quality.

HIGH VULNERABILITY

More **wildfire and flooding** are likely to significantly damage natural and human-made water infrastructure.

Water supply and drought

High vulnerability *due to projected losses in suitable water supply and increasing population, despite proactive planning, use of reclaimed water, and successful water conservation to date.*

From diversifying its water portfolio to implementing wide-ranging water conservation measures, Flagstaff has pursued many strategies to secure a sustainable long-term water supply in the face of population growth and climate change.[i] In fact, per capita water use declined approximately 40 percent between 1990 and 2016. Even so, a water supply shortfall of 28 to 40 percent is expected when Flagstaff's population exceeds 87,600. Under the most extreme planning scenario, new supplies will be required as early as 2031 to accommodate a population greater than 87,600.[ii]

[i] This is known as the Adequate Water Supply Designation, administered through the Arizona Department of Water Resources, which signifies "that Flagstaff has demonstrated physical supply availability for 100 years, legal rights to water, water infrastructure, as well as financial and water treatment capabilities." See https://www.flagstaff.az.gov/2263/Adequate-Water-Supply-Designation (accessed March 22, 2018).

[ii] City of Flagstaff delivers 10,500 acre-feet of water per year. A conservative estimate suggests an 8,000 acre-feet shortfall to accommodate new growth beyond a population of 87,600 people, which is expected around 2031. See Reference 8.

While the City's progress in water efficiency and water conservation has postponed the need for a new water source, Flagstaff's water supply remains susceptible to multiple risks as the climate changes:

- **Drought and increased temperatures:** When surface water supply runs low, the city relies more on groundwater pumping. The first groundwater well was drilled in 1954 in response to drought. The average annual temperature is projected to increase 4-5°F by 2050, driven largely by an increase in minimum temperatures. These temperature increases are expected to increase surface water evaporation and reduce soil moisture, especially in winter and spring. As a result, Flagstaff can expect overall drier conditions, an increased risk of drought, and a potential decline in Upper Lake Mary Reservoir levels. Recent scenarios of Flagstaff's future water supply and population growth suggest a new source of water may be needed as early as 2031 in the event of an extended drought or as late as 2053 in the absence of an extended drought and with additional water conservation measures.[iii]
- **Wildfire:** Currently just 20 percent of Flagstaff's water can be sourced within city limits, and the entire city can be sustained with the water in the pipes and storage tanks for just under two days. Larger and more frequent wildfires may impair water quality—by adding sediment and changing water chemistry—from the forested watersheds that currently provide 80 percent of Flagstaff's water supply. Wildfires may also burn infrastructure and isolate the city more often. Currently, in the event of a wildfire-induced power loss to the city's water distribution and treatment system, it would take two days to restore water for use in firefighting and seven days to restore drinking water once the system was refilled with water.[iv]
- **Reduced snowpack:** Average winter temperatures hover around 34.5°F in Flagstaff, and winter snowpack is an important source of aquifer recharge and surface water flows into Upper Lake Mary. However, with a 4°F increase in average winter temperature expected by 2050, more water will evaporate from the landscape than it does today and more precipitation will fall as rain rather than snow.[v] Snowpack is expected to decline 40 percent by 2041-2070,[vi] reducing water inputs to the reservoir and aquifers that currently make up Flagstaff's water supply.
- **Change in the timing of rain and snow:** Climate change has already led to fewer but more intense storms during the monsoon season. These trends may continue as temperatures warm further. Spring precipitation may also decline 20 to 40 percent by 2100, perhaps due to fewer spring storms as the jet stream shifts north.[vii] More intense storms may overwhelm soil water storage capacity and lead to increased runoff and risk of flooding. Conversely, the harder raindrops that can characterize more intense storms also prevent soil from absorbing as much water as it typically can, thereby reducing aquifer recharge.

By the Numbers: Flagstaff's Water

- The 2017 water supply was **73 percent groundwater** from local and regional wells, **22 percent surface water** from Upper Lake Mary Reservoir, and **5 percent spring water** from the Inner Basin in the San Francisco Peaks.
- **Upper Lake Mary can provide as much as 50 percent of the city's drinking water.**
- **Reclaimed water represented 22 percent** of water delivered in 2017.
- We are getting more efficient. **Per capita water use declined nearly 50percent** from 1989 to 2017.
- Despite water conservation measures, **a water supply shortfall is expected** as population grows. **Flagstaff may need another water supply** that does not affect environmental flows to ensure adequate supply for everyone for 100 years.

[iii] The 2031 scenario assumes a population of approximately 87,500, which is comparable to a continued growth rate of 1.35 to 2.2 percent. See References 6 and 8.

[iv] Providing bottled water would cost an estimated $106,641 per day, not including the costs of distribution.

[v] Results are for the period 2043-2079, compared to 1969-2005. See Figure 7 in Dominguez et al. (2012).

[vi] Snowpack is measured as April 1 snow-water equivalent. The projection is the high-emissions A2 scenario. See References 1 and 3.

[vii] In the Flagstaff area, the monsoon season makes precipitation especially difficult to model well. Seasonal precipitation projections should be interpreted with caution. For more information on Flagstaff precipitation trends and projections, see the Climate Profile.

Flagstaff's water conservation successes have made the city more resilient to the reduced aquifer recharge, surface water decline, and reduced infiltration anticipated in the coming decades. Additional efforts—indicative of Flagstaff's adaptive capacity—are underway to continue to prepare Flagstaff for future climate conditions:

- The **Water Conservation Strategic Plan** will explore the technical feasibility of extreme water conservation and community preferences for conservation.
- Several **City code changes** have incentivized efficient water fixtures, low-flush toilets, and other conservation measures. These and other efforts continue today. For example, the City's WaterWise program reduces water use at hotels, restaurants, and other businesses. The City is also working to reduce non-revenue water loss, which typically makes up 5 to 10 percent of water production.[viii]
- **Expanded reclaimed or recycled water** could come from recovering more of the discharge to Rio de Flag (70% is not recaptured currently),[ix] capture and use of stormwater runoff, and other sources. However, local communities have expressed concern about the use of reclaimed water, especially on sites sacred to tribes such as San Francisco Peaks. Currently, about 20 percent of water delivered in Flagstaff is recycled water.
- In 2005, following a drought and voter approval, Flagstaff purchased Red Gap Ranch. A three-phase study is underway to **evaluate the costs and feasibility of developing Red Gap Ranch to increase groundwater supply**. If approved, the project would be expensive to construct and would involve a 40-mile pipeline rising 2,000 feet from the ranch to Flagstaff, equipping existing wells, building four booster stations, and addressing the saltier water stored in the aquifer. This vast water source is shared with the Navajo Nation, Hopi Tribe, Arizona Public Service, and others.[x] Through an agreement with the Navajo Nation, Flagstaff could draw up to 8,000 acre-feet per year,[5] which would provide enough water until the city is built out at current rates of growth.
- To reduce reliance on the forested watersheds surrounding the city, Flagstaff plans to **drill five new in-city wells** in the next 10 years. The average well in Flagstaff costs $3 million to build.

Water is Sacred

Water and moisture are sacred to the Hopi Tribe, Navajo Nation, and other tribal communities. Many of their traditional practices and ways of life depend on the timing of moisture during the year, a cycle that is impacted by climate change. Certain vegetation or plant life used to feed animals or in ceremonies, for example, are now less likely to receive moisture to support culturally significant times of the year.

Historically, some cultural sites located near water sources were replenished naturally, but encroachment from development and drier conditions have left some land and wildlife without the water they need to flourish.

Additionally, important cultural and ceremonial sites are scattered across the land and mountains surrounding Flagstaff. Some historical and cultural sites are visited regularly, respective of each tribal nation's cultural seasons and cycles. Protecting these sites from desecration that may occur through accidental trampling or use of reclaimed water is considered honorable among the tribes.

Water quality

Medium-high vulnerability *due to the likelihood of increased sedimentation in Upper Lake Mary and the complexity and costs of reducing that risk.*

Watershed health is essential to Flagstaff's water quality: drinking water currently requires standard treatment due to the watershed's filtration and cleaning capacity. However, a variety of climate-related factors can stress the

[viii] Losses are incurred from system water leaks, hydrant flushing, and water meters that under-report water use.

[ix] Rio de Flag discharge could be recycled indirectly or directly. Indirect recycling could involve advanced water treatment before directing the treated discharge back to groundwater or Upper Lake Mary. Direct recycling could be achieved through advanced water purification and direct potable reuse, which requires significant investments in infrastructure, staff training, and other resources.

[x] This includes the Town of Winslow and local water providers at Flagstaff Ranch, Kachina Village, Doney Park, and elsewhere.

watershed's ability to filter and clean water. Drought, especially when followed by heavy precipitation and flooding, can increase sediment in Upper Lake Mary, which reduces the quality of surface water entering Flagstaff's Lake Mary Water Treatment Plant. While fire is a natural part of Flagstaff's landscape, post-fire floods, especially following stand-replacing wildfires, are of particular concern due to the possibility of long-term increases to sedimentation and organic carbon in Upper Lake Mary while plants re-establish on the burned landscape.

The potential for stand-replacing wildfires around Upper Lake Mary is considered the primary threat to future water quality. These moderate to severe wildfires can burn so hot that water can no longer infiltrate soil, causing even more sediment to wash into surface water supplies. These fires can also incinerate soil organisms and nutrients, significantly increasing the time and costs involved in reestablishing the vegetation that keeps soil on the landscape and out of Upper Lake Mary. A stand-replacing wildfire near Upper Lake Mary could render the water supply unusable until the reservoir is dredged or the downstream treatment facility is upgraded to handle the reduced water quality.[7] To reduce risks to the water supply and other valued resources from stand-replacing fires, forest thinning is planned in the area around Upper Lake Mary; however, much of this work has been delayed.

The other major climate-related concern for Flagstaff's future water quality is that the City's sewer collections system and water reclamation facilities currently require a certain amount of water to move and process waste effectively. If continued indoor water conservation or too little precipitation leaves too little water for treatment, water quality could be affected. To address this potential risk to water quality, the Water Conservation Strategic Plan will examine limitations in the current sewer collections system and treatment process.

Water and wastewater infrastructure

High vulnerability *due to critical infrastructure at risk from a single, large fire and the costs of securing additional water capacity.*

Flagstaff's water system includes two water reclamation facilities, two water treatment facilities, 24 active wells, five main pressure zones, three concrete storage reservoirs, six steel water storage tanks, and seven pump stations.[5] The City's increased water rates have been used to rebuild aging infrastructure such as water and sewer lines built in the early 1900s. Most of the wastewater collection system was built after 1960. The two reclamation facilities together have sufficient capacity (10 million gallons per day) to accommodate Flagstaff's population to at least the mid-2030s.[xi]

If the forests that clean and store water above Upper Lake Mary experience one of the larger, more frequent wildfires anticipated in Flagstaff's future, the costs to address the impacts could be significant. A cost avoidance study estimated that a wildfire burning the basin above Lake Mary could require $17 million to $37 million to immediately drill 11 new wells, dredge Lake Mary and expand treatment facility capacity, or both.[7] Similarly, if a wildfire resulted in a power loss affecting water distribution and treatment, the City could lose $48,000 per day in revenue and incur significant costs to provide drinking water.[xii] The water wells and pump stations in the forested watershed outside of Flagstaff and the network of pipes linking them to Flagstaff homes, businesses, and other buildings are also at risk from wildfire. To reduce the likelihood of wildfire damage, the forest near pump stations has been thinned, and there are plans in place to protect the pumping stations and pipes in the event of wildfire. However, these plans currently are unfunded. Absent additional preventive measures, the potential for larger, more frequent wildfires will increase the risk of damage.

[xi] The 2017 Report to the Water Commission (see Reference 6) stated this capacity is "projected to serve the City of Flagstaff until 2035 or approximately a population of 100,000 (Sewer Master Plan, 2015 Brown & Caldwell)."

[xii] Providing bottled water would cost an estimated $106,641 per day, not including the costs of distribution.

References

[1] D. R. Cayan, M. Tyree, K. E. Kunkel, A. Gershunov, J. Barsugli, A. J. Ray, M. Anderson, J. Russell, B. Rajagopalan, I. Rangwala and P. Duffy, "Future climate: Projected average," Island Press, Washington, DC, 2013.

[2] City of Flagstaff, "City of Flagstaff Resiliency and Preparedness Study," Flagstaff, AZ, 2012.

[3] P. W. Mote, A. F. Hamlet, M. P. Clark and D. P. Lettenmaier, "Declining mountain snowpack in western North America," *Bulletin of the American Meteorological Society,* vol. January, pp. 39-49, 2005.

[4] City of Flagstaff, "City of Flagstaff Water Infrastructure Master Plan: Executive Summary," City of Flagstaff, Flagstaff, 2014.

[5] Arizona Rural Policy Institute, "Flagstaff Watershed Protection Project: Cost Avoidance Study," Arizona Rural Policy Institute, 2014.

[6] City of Flagstaff, "Report to the Water Commission: Water, Wastewater, Reuse and Stormwater Annual Report," City of Flagstaff, Flagstaff, 2017.

[7] Brown and Caldwell, "Executive Summary: City of Flagstaff Sewer Master Plan," City of Flagstaff, Flagstaff, 2015.

[8] E. Young, Interviewee, *Water Resources Manager, City of Flagstaff.* [Interview]. 22 March 2018.

Tourism & Recreation

Vulnerability to Climate Change

As snowpack declines, losses are expected to snow-based tourism and recreation. Visitor numbers may increase in the summer, when wildfire or drought could pose temporary threats. Our businesses and services will need to be ready to continue to diversify tourism and recreation activities, and prepare for low-snow years.

In a changing climate, Flagstaff communities are likely to face:

HIGH VULNERABILITY

Significant **snowpack loss** will decrease winter recreation and tourism.

LOW-MEDIUM VULNERABILITY

More **wildfire, drought, or extreme heat** may temporarily reduce visitation in summer, spring, and fall.

Winter recreation and tourism

High vulnerability *due to significant loss in snowpack and few substitutes for snow-based recreation and tourism.*

Flagstaff's winter recreation and tourism depends on a robust snowpack that is already declining as winter temperatures warm.[2] On average, 104,900 people visit Snowbowl each year.[i] Already, low-snow years generate fewer visits from skiers, fewer jobs, less labor income, and less value added to the economy than high-snow years.[5,10] From November 1999 to April 2010, there were 29 percent fewer skiers visiting resorts across Arizona in low-snowfall years than in high-snowfall years, resulting in an $18.6 million loss to the economy and 226 fewer jobs on

FLAGSTAFF: 14TH MOST VISITED U.S. CITY

Flagstaff is a year-round destination for U.S. and international travel:

- In 2016, top destinations in and around Flagstaff such as the Grand Canyon, Painted Desert, Lowell Observatory, Arizona Snowbowl, and Lake Powell drew **4.8 million visitors** to the city. This represented a 20 percent increase from 2014.[12]
- In 2017, Flagstaff was the **14th most-visited city in the U.S.**, with 40 percent of visitors from Arizona and 49 percent from other U.S. states.[6]

Visitors support an estimated **8,000 jobs** and bring **$500 million** to the local economy.[6] Over 5,400 people (14.7%) are directly employed in tourism and hospitality, and Flagstaff boasts more hotel rooms per capita than Las Vegas.[4,7]

By 2050, at least 9.5 million people are expected to visit northern Arizona each year.[12]

[i] One-third of visitors stay overnight. See Reference 10.

average in those low-snowfall years.[ii] From 2001 to 2016, similar impacts from low snowfall were reported in Arizona.[iii]

Regions—and ski resorts—with average winter temperatures between 23°F and 41°F are most vulnerable to snow loss in the future because they tend to receive less snow than their high-elevation, high-latitude counterparts.[5,9,11] Currently, Flagstaff's average winter temperature is 34.5°F, and is expected to increase approximately 4°F by 2050. Some winters may exceed 41°F. As a result, more precipitation is expected to fall as rain rather than snow,[iv] driving an estimated 40 percent decline in snowpack by 2041-2070 compared to the 1971-2000 period.[v]

The Southwest's ski areas are also projected to lose comparatively more snowpack than U.S. ski resorts with colder climates.[1] One estimate suggests daily revenue losses ranging from 7 percent with major adaptation efforts to 100 percent with no adaptation efforts.[3] Snowmaking will likely remain viable all season at Snowbowl until 2030 and only viable in the coldest months by 2050. By 2080, without snowmaking efficiency improvements, snowmaking will be increasingly expensive and likely no longer viable.[10,11] Snowbowl may need to redirect resources to recreation in other seasons.[11]

Despite having few substitutes for snow-based recreation and tourism, Flagstaff's efforts to diversify tourism opportunities year-round help reduce economic impacts in low-snowfall years. For example, despite a dry year last year, winter visitation and visitor spending did not plummet. Diverse marketing messages may have played a role: they were focused on Flagstaff's craft beer and food culture, the Museum of Northern Arizona, dark skies, Lowell Observatory, and surrounding monuments.

Summer recreation and tourism

Low-medium vulnerability *due to a robust industry that could accommodate or benefit from climate-related changes in visitation.*

Hotter summers in southern Arizona and fewer snow-based recreation opportunities locally may shift some of Flagstaff's recreation and tourism to the summer months and shoulder seasons (spring and fall).[11] National economic studies suggest gains in warm-season tourism may compensate for losses in cold-season tourism.[3] However, Flagstaff's

Snowbowl Visitation Trends

On average, 104,900 people visited Snowbowl each year from 1981 to 2006. Average snowfall during this timeframe was 234 inches per year. While other factors such as general economic health and snowmaking affect the decision to visit Snowbowl, the number of visitors generally peaked in the highest-snowfall years and sank in low-snowfall years:

- **Over 170,000 people visited Snowbowl when snowfall exceeded 330 inches per year** (the 1991-1992, 1992-1993, 1997-1998, and 2004-2005 seasons).
- **Fewer than 30,000 people visited Snowbowl when snowfall was below 118 inches per year** (the 1983-1984, 1995-1996, and 2001-2002 seasons).

[ii] The study compares the two lowest-snowfall years with the two highest-snowfall years. See Reference 9.

[iii] On average, 310,251 skiers visited Arizona each year from 2001 to 2016. Compared to the average, the bottom five snow years saw 11% fewer visits, 240 fewer jobs, $8.6 million less in wages, and $14.1 million less to the economy. The top five snow years saw a 30% boost in visits, 365 more jobs, $13 million more in wages, and $21.5 million more to the economy compared to the average snowfall year. In 2010, a higher snow year, snowplay visitors at Wing Mountain and dispersed sites brought 221 jobs and $16.2 million to the Flagstaff area economy. In 2016, a lower snow year, winter tourism brought 1,343 jobs and $79 million to the Arizona economy. See References 5 and 16.

[iv] Results are for the period 2043-2079, compared to 1969-2005. See Figure 7 in Reference 1.

[v] Snowpack is measured as April 1 snow-water equivalent (SWE). The projection uses the high-emissions A2 scenario. For the White Mountains, Gergen et al. (2017) also projected a 95% decline in snowpack (measured as SWE) by the 2080s (high-emissions scenario). See References 2 and 8.

already-robust tourism infrastructure may need additional capacity to meet higher demand. With visitors concentrated in the warm season, unintended environmental stresses such as greater water demand or increased trampling of natural areas may also occur.[11] Microbiotic crust—a fragile, nutrient-rich microscopic layer covering many Colorado Plateau landscapes—is more sensitive to trampling during dry conditions.[vi]

Additionally, the potential for more visitors in summer, spring, and fall due to rising temperatures elsewhere may be constrained by other climate change impacts that reduce access, increase safety risks, or impair scenery:

- **Wildfire:** Sunset Crater National Monument is estimated to have lost 12,000 visitors and $225,000 in local economic spending due to the 2002 wildfire season (most recent data available).[11] However, this kind of impact is not typically long-lasting; studies show that at popular destinations in other parts of the country, tourism has returned to pre-fire levels within one year.[vii] Hikers in particular may return to recently burned areas to view wildflowers.[viii]
- **Drought:** Visits to Lake Powell and Glen Canyon National Recreation Areas have declined in response to a drop in reservoir levels: 500,000 fewer visitors, and a loss of $32.1 million in visitor spending and 758 jobs were reported during the extreme drought in 2003.[11] Compared to other water recreation, boating is especially sensitive to water levels.[3]
- **Extreme heat:** The risk of heat-related illness and death may increase in desert destinations such as Grand Canyon National Park, resulting in fewer visitors or an increased need for emergency services. Winter tourism in desert areas, however, may increase as temperatures warm.[11]
- **Reduced water supply and quality:** River-based tourism such as rafting and fishing may decline as streamflow declines, warmer water stresses fish, and more sediment enters waterways after wildfires.[3,11] Given the popularity of the Colorado River, reduced flows there could be especially detrimental to regional river-based tourism.[ix] Hikers, mountain bikers, and backpackers may also choose other destinations if water sources near paths dwindle or disappear.[3]

[vi] Microbiotic crust is the primary source of nitrogen in the Colorado Plateau. See References 13-15.

[vii] Visitation to Yellowstone National Park fell 15% after the 1988 wildfires, but recovered to nearly pre-fire levels the year after. See Reference 3.

[viii] In Colorado, hikers returned to wildfire areas sooner than mountain bikers, who may have had concerns about path conditions. See Reference 11.

[ix] If Colorado River water were completely lost for one year, Arizona's accommodation & food services sector and arts, entertainment, & recreation sector could lose an estimated $9 billion in gross state product (2014 dollars) and 166,205 jobs. See Reference 17.

References

[1] S. Wi, F. Dominguez, M. Durcik, J. Valdes, H. F. Diaz and C. L. Castro, "Climate change projection of snowfall in the Colorado River Basin using dynamical downscaling," *Water Resources Research,* vol. 48, p. W05504, 2012.

[2] P. W. Mote, A. F. Hamlet, M. P. Clark and D. P. Lettenmaier, "Declining mountain snowpack in western North America," *Bulletin of the American Meteorological Society,* vol. January, pp. 39-49, 2005.

[3] D. Morris and M. Walls, "Climate Change and Outdoor Recreation Resources," Resources for the Future, Washington, DC, 2009.

[4] Greater Flagstaff Chamber of Commerce, "Flagstaff Labor Statistics," 2018. [Online]. Available: https://www.flagstaffchamber.com/economic-development/labor. [Accessed 28 February 2018].

[5] M. Hagenstad, E. Burakowski and R. Hill, "The economic contributions of winter sports in a changing climate," Protect Our Winters, 2018.

[6] Flagstaff Convention & Visitors Bureau, "Fiscal Year 2017 Annual Report. Fiscal Year 2018 Marketing Plan.," Flagstaff Convention & Visitors Bureau, Flagstaff, 2018.

[7] City of Flagstaff Economic Development Department, "Tourism," 2018. [Online]. Available: http://www.chooseflagstaff.com/key-industries/tourism. [Accessed 28 February 2018].

[8] D. R. Cayan, M. Tyree, K. E. Kunkel, A. Gershunov, J. Barsugli, A. J. Ray, M. Anderson, J. Russell, B. Rajagopalan, I. Rangwala and P. Duffy, "Future climate: Projected average," Island Press, Washington, DC, 2013.

[9] E. Burakowski and M. Magnusson, "Climate impacts on the winter tourism economy in the United States," Natural Resources Defense Council and Protect Our Winters, 2012.

[10] R. H. Bark, B. G. Colby and F. Dominguez, "Snow days? Snowmaking adaptation and the future of low latitude, high elevation skiing in Arizona, USA," *Climatic Change,* vol. 102, pp. 467-491, 2010.

[11] R. H. Bark, "Assessment of climate change impacts on local economies," Sonoran Institute and Lincoln Institute of Land Policy, 2009.

[12] City of Flagstaff, "Flagstaff Regional Plan 2030: 2016 Annual Report," City of Flagstaff, Flagstaff, AZ, 2017.

[13] D. N. Cole, "Trampling disturbance and recovery of cryptogamic soil crusts in Grand Canyon National Park," *Great Basin Naturalist,* vol. 50, no. 4, pp. 321-325, 1990.

[14] A. M. Faist, J. E. Herrick, J. Belnap, J. W. Van Zee and N. N. Barger, "Biological soil crust and disturbance controls on surface hydrology in a semi-arid ecosystem," *Ecosphere,* vol. 8, no. 3, p. e01691 (13 pp.), 2017.

[15] R. D. Evans and J. Belnap, "Long-term consequences of disturbance on nitrogen dynamics in an arid ecosystem," *Ecology,* vol. 80, no. 1, pp. 150-160, 1999.

[16] The Arizona Hospitality Research & Resource Center, "Flagstaff Snowplay Study," Northern Arizona University, Flagstaff, 2010.

[17] T. James, A. Evans, E. Madly and C. Kelly, "The Economic Importance of the Colorado River to the Basin Region," Arizona State University, Tempe, 2014.