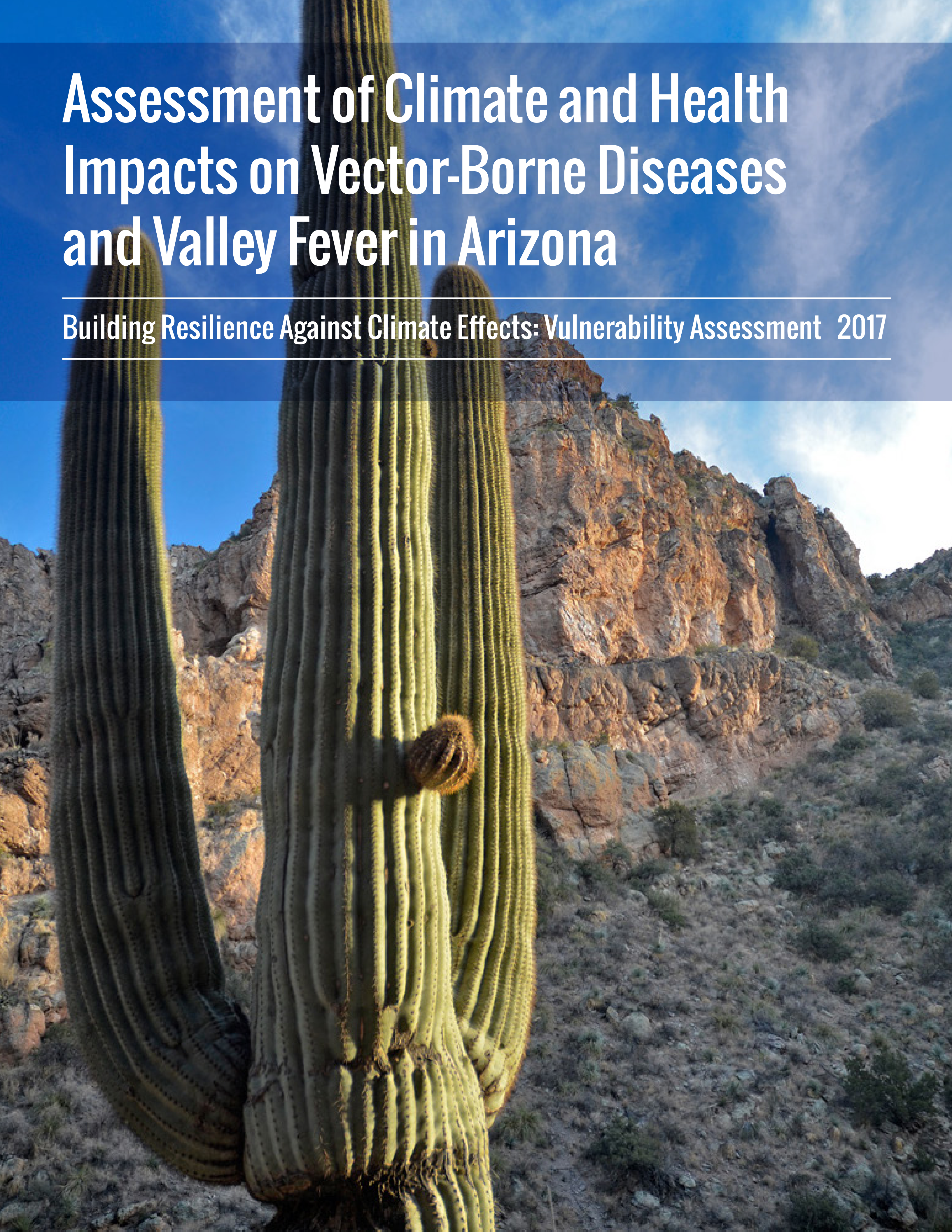
Assessment of Climate and Health Impacts on Vector-Borne Diseases and Valley Fever in Arizona

Building Resilience Against Climate Effects: Vulnerability Assessment 2017



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ARIZONA DEPARTMENT OF HEALTH SERVICES

THE UNIVERSITY OF ARIZONA

CLIMAS Climate Assessment for the Southwest A NOAA RISA TEAM

THE UNIVERSITY OF ARIZONA Institute of the ENVIRONMENT

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Executive Summary

To facilitate state and local health departments' preparation for the health effects of climate-sensitive hazards, the Centers for Disease Control and Prevention has developed the Building Resilience Against Climate Effects (BRACE) framework. The BRACE framework outlines five steps (Figure 1) that health officials can follow, in order to develop plans and programs to communicate with the public and prepare for the health effects of climate hazards with partner organizations. Sixteen US states and two large cities have begun efforts to implement the BRACE framework and complete the five-step process. The ultimate goal of the BRACE framework is to provide resources to health departments for the development of mitigation and adaptation plans specifically suited for their communities.

Figure 1. Steps in the BRACE (Building Resilience Against Climate Effects) framework (Hess et al. 2014)

The Arizona Department of Health Services, in collaboration with the University of Arizona, completed the first step of the BRACE framework for vector-borne diseases and valley fever. The diseases reviewed were selected based on their burden in Arizona and the degree to which they are expected to be affected by climate change.

A Vulnerability Assessment helps describe health hazards associated with current and future climate. This Assessment focuses on the climate effects on vector-borne disease and Valley fever in Arizona, with the goal of first explaining how climate influences these hazards, and then identifying populations with greater risks from the effects of these specific diseases. The Vulnerability Assessment is divided into two sections:

a. An **Evidence** section, with a description of the association between climate and vector-borne diseases and valley fever, specifically highlighting those diseases for which there is scientific evidence of changes or expected changes.

b. The **Vulnerability Assessment**, with disease-specific information about the Social Vulnerability, which aids in understanding social vulnerabilities for these health hazards. For this assessment, we identified two diseases in Arizona—West Nile virus (WNV) disease and coccidioidomycosis (also known as valley fever)—that inflict a considerable burden on the population of Arizona and are expected to be influenced by changes in the climate. We then applied the established methods for AZ at the Census block level and overlaid the additional risk factors associated with these two diseases.

North Maricopa Mountain Wilderness, Arizona. Photo Credit: Bob Wick (Bureau of Land Management).

Conclusion

This vulnerability assessment focused on infectious diseases of public health importance in Arizona that are or are expected to be effected by temperature and precipitation. The risk for many infectious diseases are influenced by climate. Warmer and wetter years have been linked with increases in plague incidence (Ari et al. 2008). In a complex association between precipitation, vegetation, and rodent host activity, climate influences the occurrence of Hantavirus pulmonary syndrome (Parmenter et al. 1999; Engelthaler et al. 1999). Because of the tight association between the ticks that transmit Rocky Mountain spotted fever and houses and dogs, the climate link is a bit more tenuous, however a seasonal trend with peaks in July through September has been observed in Arizona (Treager et al. 2015).

For two diseases, the association between weather and disease risk are more strongly understood: West Nile virus disease and Valley fever. Because precipitation, in addition to human activity, creates habitat for immature mosquitoes and temperature influences development rates, mosquito-borne West Nile virus disease is linked with weather. Precipitation (both increased and drought), wind aerosolizing Coccidioides spores, and temperature have been associated with Valley fever incidence in Arizona, however the strength and nature of the association is localized (Park et al. 2005; Comrie 2005; Talamantes et al. 2007; Zender and Talamantes 2006).

Moreover, because of the burden in the US, these latter two diseases have been relatively well studied and spatially explicit risk factor information were available. When applying an established method to understand social vulnerability for these diseases at a local scale (U.S. Census blocks) and overlaying disease specific risk factors, vulnerability varied across the state and within counties. No strong trends were identified from the map analysis. Further stakeholder engagement may be needed to better characterize risk. Local perspectives may shed light on vulnerability factors and help with decision planning for adapting to these hazards.

Introduction

Consensus among climate scientists suggests that the world is already experiencing increased temperature and variability in precipitation and humidity. The Fourth and Fifth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC) climate projections predict North America will continue to experience warming and changes in humidity and precipitation patterns, drought, and flooding as result of climate change (IPCC, 2014; IPCC, 2007; Greer et al. 2008). The IPCC estimates a ninety percent probability of warming in all of North America by the year 2100 (IPCC, 2007; Hess et al. 2008). The change of these weather patterns and the associated health hazards will vary by geographical location (Hess et al. 2008).

The southwestern United States (Arizona, California, Colorado, Nevada, New Mexico, and Utah), in particular, is predicted to experience an increase in the frequency, duration, and intensity of extreme heat events in addition to a decline in regional precipitation (Cayan et al. 2013). Average temperatures in the Southwest are projected to be 3°F (1.7°C) higher than previous average temperatures by the end of the 21st century, especially in the summer and fall (Cayan et al. 2013).

Extreme weather events will have both direct and indirect consequences on health (Greer et al. 2008). Direct effects include heat-related morbidity and injuries where urban cities are at risk of urban heat island (UHI) effects (Greer et al. 2008; Hess et al. 2008; Luber and McGreehin, 2008; Luber and Prudent, 2009). In March 2015, the Arizona Department of Health Services and Arizona State University released a Climate Health Profile Report addressing the health risks of extreme heat events. The report used downscaled climate projections for Arizona and identified residents who are most susceptible to health outcomes that are related to extreme heat and poor air quality (Chhetri et al. 2015). Indirect effects of extreme heat also include from power outages and damages to infrastructure. The potential for increased burden on the healthcare system, especially Emergency Medical Services and hospitals, may extend response times and possibly lead to suboptimal care, thus increasing the overall risk of morbidity and mortality.

The pathways between climate and human health are interrelated and complex (Figure 2). Beyond the direct effects of climate, development, land use, adaptation, and mitigation influence human vulnerability (Chhetri et al. 2015). Expected changes in climate may exacerbate preexisting conditions, with negative impacts on certain chronic diseases like cardiovascular and respiratory diseases. Indirect effects of climate hazards include variations in incidence and distribution of infectious diseases, including vector-borne and zoonotic diseases with environmental reservoirs (Greer et al. 2008). Whether direct or indirect, the health effects resulting from increases in the frequency of extreme weather events will be regional, with very different health outcomes affecting different populations (Hess et al. 2008). The climate conditions most relevant to the US Southwest are extreme heat, air pollution, and flooding (Chhetri et al. 2015).

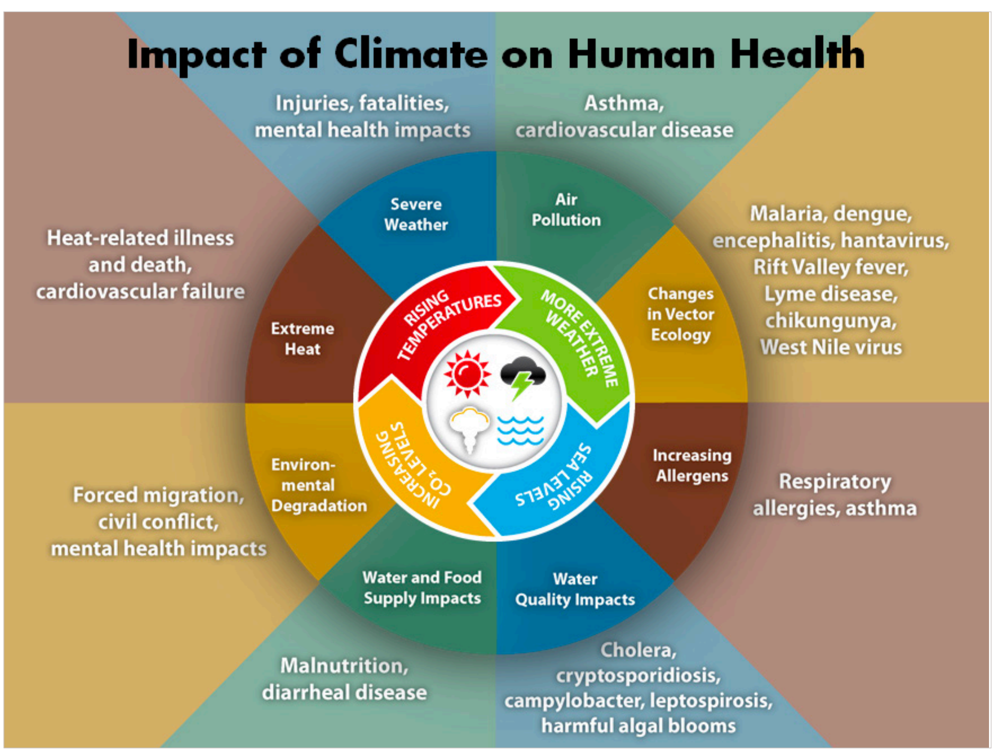


Figure 2. Conceptual Pathways of Climate and Health. Source: CDC Climate Effects on Health – **www.cdc.gov/climateandhealth/effects/**

In public health, vulnerability is defined as "the degree to which a system is susceptible to injury, damage, or harm" (Smit et al. 2001; Managan et al. 2014). With respect to climate, the Third National Climate Assessment defines vulnerability as "a function of the character, magnitude, and rate of climate variations to which a system is exposed, its sensitivity, and its adaptive capacity" (Bierbaum et al. 2014). The purpose of a climate vulnerability assessment is to identify health risks associated with climate-sensitive hazards. For health departments, this means identifying people and places in their jurisdictions that are at the greatest risk, and taking necessary actions to reduce harm. Therefore, a vulnerability assessment is critical for planning and responding to current and future climate challenges.

While climate models are increasingly accurate at finer scale predictions, their accuracy is affected by a community's capacity, to adapt and respond. Social factors, such as a community's demographics, financial resources, and even their geographic location can put limitations on adaptive capacity and influence vulnerability (Ebi et al. 2009; Ebi et al. 2013). Therefore, developing a response plan must be done at multiple levels and with the participation of relevant stakeholders (Frumkin et al. 2008; Ebi et al. 2013).

The BRACE framework, developed by CDC, was designed to prepare health departments to respond to climate exposures and the associated health risks. An assessment starts by reviewing the evidence supporting an association between the health hazard and climate hazard, then identifying those specific diseases of concern, and lastly–conducting a population–specific vulnerability assessment.

Incidence of Selected Diseases in the Southwest

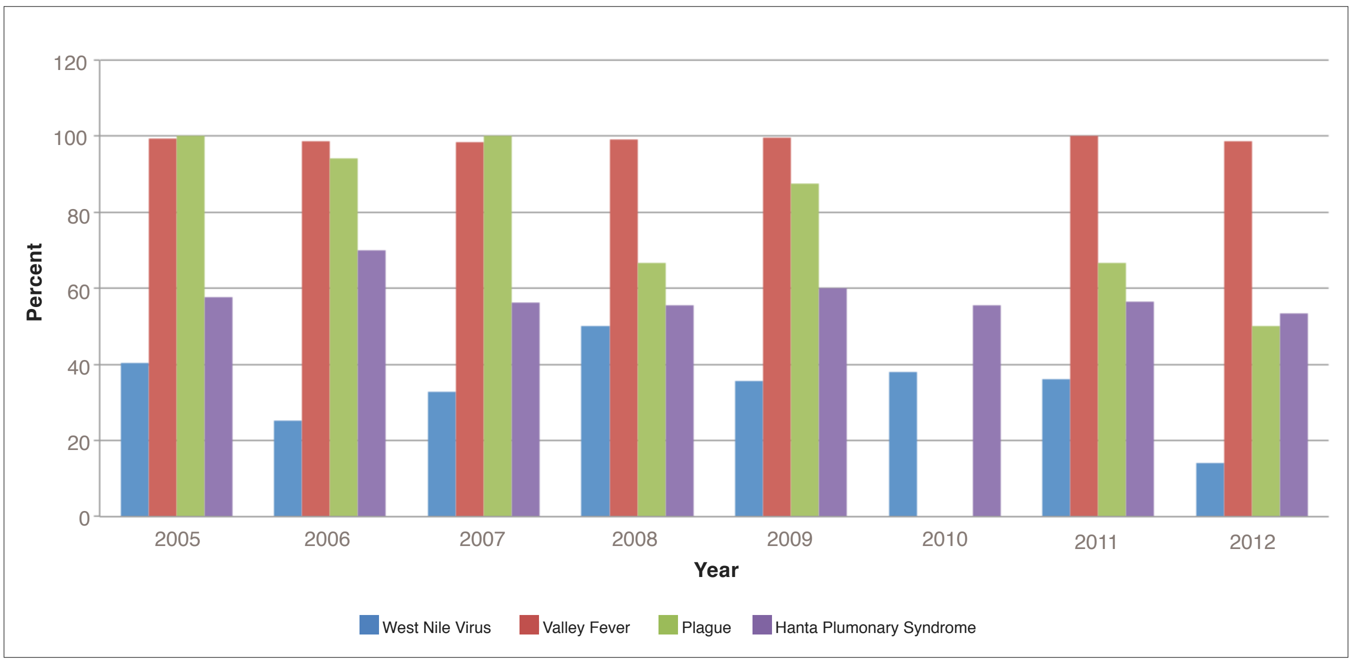


Figure 3. Incidence of selected diseases in the Southwest as a percentage of the total cases in the United States. The proportion of the total cases in the US Southwest of West Nile virus disease, Valley fever, and Hanta virus pulmonary syndrome reported annually from the Southwest to the CDC are fairly consistent from year to year. Plague fluctuates, but this is expected for a disease with few cases each year. Only two cases of plague were reported in the US in 2010; both in Oregon. In 2010, Valley fever was not-notifiable.

Evidence

The first step in developing a plan to respond to changes in infectious diseases resulting from shifts in climate is to understand how they are influenced by climate (e.g. temperature and precipitation) and the current burden of these diseases.

Climate Related Infectious Diseases in the U.S. Southwest

The Southwestern United States is not just unique in its climate, but also in the diseases it experiences. Almost 100 percent of Valley fever cases and the vast majority of plague cases occur in this region (CDC Summary of Notifiable Diseases, 2005-2012; Figure 3). In addition, despite that only 18.2 percent of the US population lives in this region, approximately 28.8 percent of the West Nile virus and 58.9 percent of Hanta Virus Pulmonary Syndrome (HPS) cases occur in the Southwest (CDC Summary of Notifiable Diseases, 2005-2012; Figure 3).

Climate-Related Diseases Particular to Arizona

Arizona is the sixth largest state in the United States with respect to area and has one of the fastest growing populations (Brewer and Humble, 2014). Typical of the Southwest, Arizona is faced with a unique set of climate related health concerns. In 2013, 180 infectious disease outbreaks occurred in Arizona alone, 81 percent of which were transmitted from person to person (Arizona Department of Health Services, 2013a). Approximately 68 percent of the reported infectious diseases cases occurred between January and May (Arizona Department of Health Services, 2013a). Schools and/or childcare facilities accounted for 38 percent of the outbreaks, and an additional 40 percent occurred in hospitals or assisted living facilities; this indicates the sensitivity of certain vulnerable groups to these reportable infectious diseases (Arizona Department of Health Services, 2013a).

Incidence of Selected Diseases: Arizona vs. Total U.S.

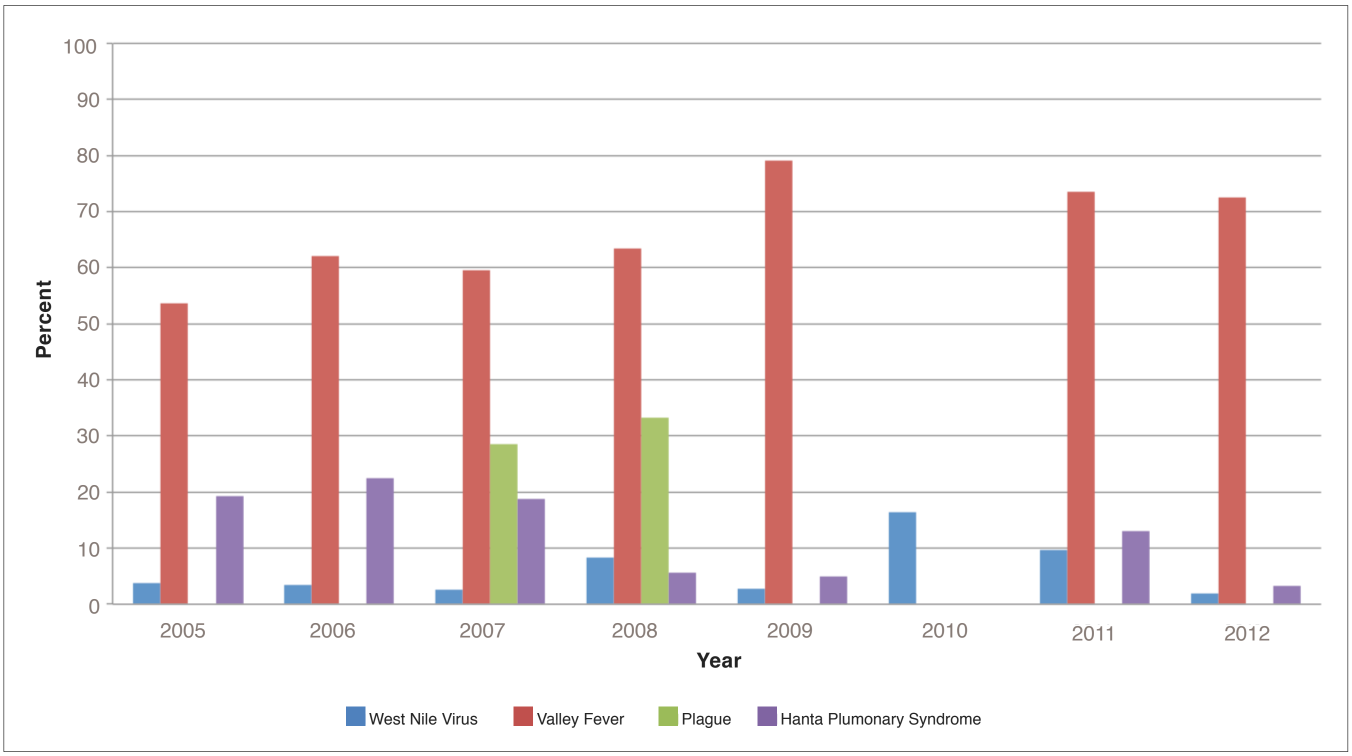


Figure 4. Incidence of selected diseases in Arizona as a percentage of the total cases in the United States.

Arizona accounts for approximately 2.1 percent of the total US population, yet 69.0 percent of Valley fever cases were reported in Arizona over from 2005 to 2012 (CDC Summary of Notifiable Diseases, 2005-2012; Figure 4). This is approximately 6,672 cases per year (ADHS Summary of Notifiable Diseases, 2001-2014). Compared to the rest of the US, approximately 4.2 percent of total cases of West Nile virus disease and 12.4 percent of the total reported Hantavirus pulmonary syndrome (HPS) cases were reported to be from Arizona (CDC Summary of Notifiable Diseases, 2005-2012; Figure 4). A review of vector-borne diseases in Arizona would be remiss to exclude Rocky Mountain spotted fever (RMSF), even if the association between this disease and climate in Arizona is weak: approximately 22 cases of RMSF are reported annually in Arizona (ADHS Summary of Notifiable Diseases, 2001-2014).

Case Studies: Diseases of Concern

Because the environment has such a significant role in the seasonal dynamics and spatial distributions of disease vectors, it is expected that climate change will affect the incidence of vector-borne disease. Similarly, the growth and dispersal of the soil-living fungi *(Coccidioides immitis and Coccidioides posadasii)* that cause Valley fever is controlled by weather patterns.

Fluctuations in weather patterns affect vector-borne and soil-borne fungal diseases in three significant ways: through changes in the ranges and/or abundance of vectors and reservoirs, in the possible extension of transmission cycles, and introduction of the pathogens or vectors to new regions (Gage et al. 2008; Greer et al. 2008). While there may be small-scale extinctions or reductions, generally, the distribution of vectors is expected to widen across the US (Gubler et al. 2001; Patz and Reisen, 2001).

We use West Nile virus disease and Valley fever as case studies of diseases expected to be affected by climate change in Arizona. These two diseases were selected primarily for their impact in the state but also because the association between the disease and climate has been well studied.

West Nile Virus (WNV) disease is a vector-borne zoonotic disease. It is maintained by multiple mosquito species in an avian cycle (mosquitoes biting and infecting birds) with humans and other animals as incidental hosts (Greer et al. 2008). Most mammals do not develop enough virus in their blood to infect mosquitoes and thus do not contribute to the maintenance of the transmission cycle. Among humans, symptoms of WNV disease include acute febrile illness with headache, myalgia or arthralgia, and gastrointestinal issues (Hayes et al. 2006). There are approximately 2,548 cases of West Nile virus disease per year in the US (estimated from CDC Summary of Notifiable Diseases, 2005-2012). Mortality occurs primarily among the approximately 1% of cases who develop the more severe West Nile neuroinvasive disease, which is further delineated into WN encephalitis (case fatality rate = 20%) or WN poliomyelitis (case fatality rate = 10-50%; Sejvar 2007).

West Nile virus was introduced to the US in 1999 in New York City (CDC, 2013a; Carnes and Ogneva-Himmelberger, 2012; Epstein, 2001). Transmission has since been reported in all 48 contiguous states with evidence of transmission in humans, mosquitoes, birds, horses, and other mammals reported in 96 percent of US counties (CDC, 2013a).

At least 65 different mosquito species have been found to be capable of being infected with WNV, but not all are capable of transmitting the virus because of host feeding preferences (CDC, 2013a). *Culex* species are primarily involved in transmission of human disease: *Culex pipiens* mosquitoes in the northeastern part of the country, *Culex quinquefasciatus* in the southern US, and *Culex tarsalis* in the West (CDC, 2013a). *Cx. tarsalis* and *Cx. quinquefasciatus* overlap in the Southwest (CDC, 2013a; Reisen et al. 2008a) and *Cx. pipiens* and *Cx. quinquefaciatus* overlap in the Mid-Atlantic (Huang et al. 2011).

Image 1. The three primary WNV vectors in the US, *Culex pipiens*, *Culex quinquefasciatus*, and *Culex tarsals* (left to right). Sources: **http://phil.cdc.gov/phil/details.asp**. Photo Credit: James Gathany

Both *Cx. pipiens* and *Cx. quinquefasciatus* are urban mosquitoes and generally breed in artificial containers (Bowden et al. 2011; DeGroote and Sugumaran, 2012). *Culex tarsalis* is associated with agricultural land covers and rural landscapes (Bowden et al. 2011; DeGroote and Sugumaran, 2012; Cardenas et al. 2011).

Image 2. Example of artificial containers that serve as habitats for immature Cx. pipiens mosquitoes. The larvae are observable in the glass with rain water (left image). Similar containers are utilized by Cx. quinquefasciatus. Source: **http://phil.cdc.gov/phil/details.asp**. Photo Credit: James Gathany.

Incidence of WNV per 100,000 by County, 2001-2014

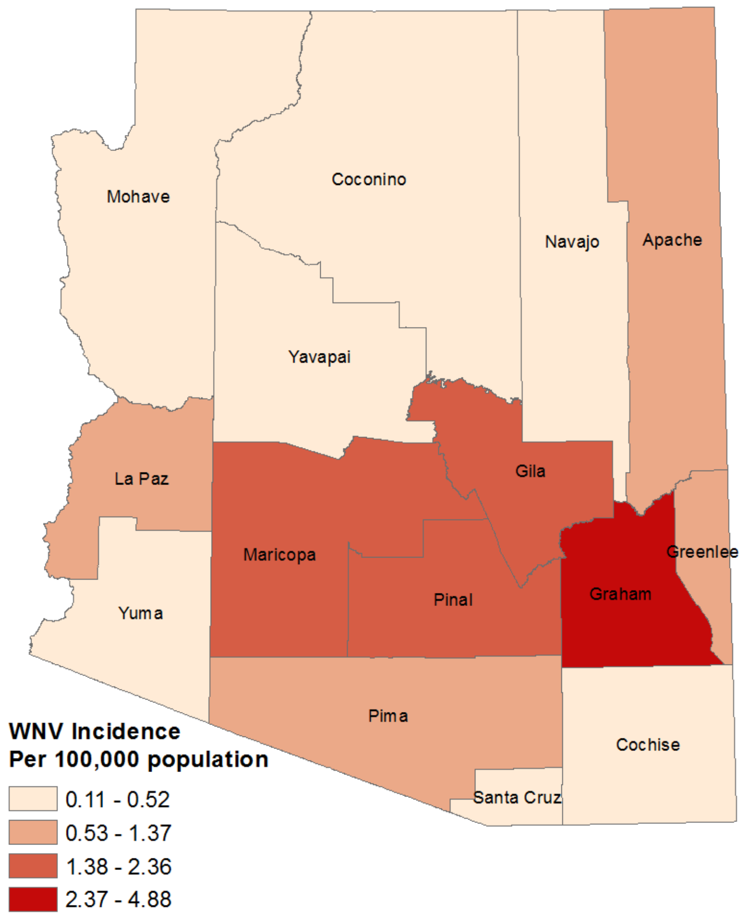


Figure 5. Incidence of WNV in Arizona counties from 2001-2014. Data Source: ADHS Notifiable Diseases, 2001-2014.

Within Arizona, two southern Arizona counties (Graham and Gila Counties, Figure 5) had the highest incidence of WNV disease, according to annual reported cases in a fourteen-year period. These two counties are among the least populated in Arizona, with 37,220 and 53,597 residents in Graham and Gila, respectively (**www.census.gov**). The incidence rate for WNV disease during the fourteen-year period in Graham County was approximately 4.9 cases per 100,000 persons, with an average of two cases reported annually. In Gila County, the incidence rate for WNV disease during the same fourteen-year period was approximately 2.4 cases per 100,000 persons, for a total of 18 cases (~1 case per year).

Relevance to Climate: Immature (egg, larval and pupal stages) mosquitoes develop in aquatic environments. Their life cycle and survival are contingent upon these water sources remaining available until the immature life stages are completed and the adults emerge. The availability of water for immature mosquitoes to develop, as well as the immature development rate, survival, and behavior of all mosquito life stages are primarily driven by temperature. Warmer temperatures tend to yield faster development, but upper and lower temperature thresholds halt development and reduce survival of all mosquito life stages. A greater abundance of mosquitoes increases the probability of both infected and non-infected bites, and, as a consequence, an increase in disease transmission.

Beyond the direct effects of temperature and water availability on the development and survival of mosquitoes, (which is associated with their abundance and activity), the timing of the events is critical. The effect of warming in the winter, when, in most of the US, mosquito populations are less active, will be different than in earlier spring, when mosquito populations are beginning to become active. Similarly, winter rains will have a different effect than summer rains, when mosquitoes are more active. Thus not only warming or changes in precipitation, but the timing of those events influence mosquito abundance by affecting the number of generations produced each year, and also through the effects on host availability and host seeking activity. And, as previously mentioned, changes in mosquito abundance, mosquito survival, and mosquito behavior has a direct impact on disease transmission.

Plague is a flea-borne rodent disease that occasionally affects humans through bites from an infected flea or through the inhalation of the pathogen, *Yersinia pestis*, that becomes airborne from a coughing infected host. Among humans, plague presents in one of three forms: bubonic, pneumonic, or septicemic. Clinical symptoms of plague vary by exposure; common symptoms include fever, fatigue, and cough (Mead, 2014). In the US, plague occurs from the Pacific coast to western edge of the Great Plains; with the largest numbers of cases in New Mexico, Arizona, California, and Colorado (CDC Summary of Notifiable Diseases, 2005-2012; Brown et al. 2010). The last reported case in Arizona was in 2008 (ADHS Summary of Notifiable Diseases 2001-2014). Recently, only Apache and Coconino Counties reported plague cases in Arizona (ADHS Summary of Notifiable Diseases, 2001-2014; Figure 6).

Total Number of Plague Cases by County 2001-2014

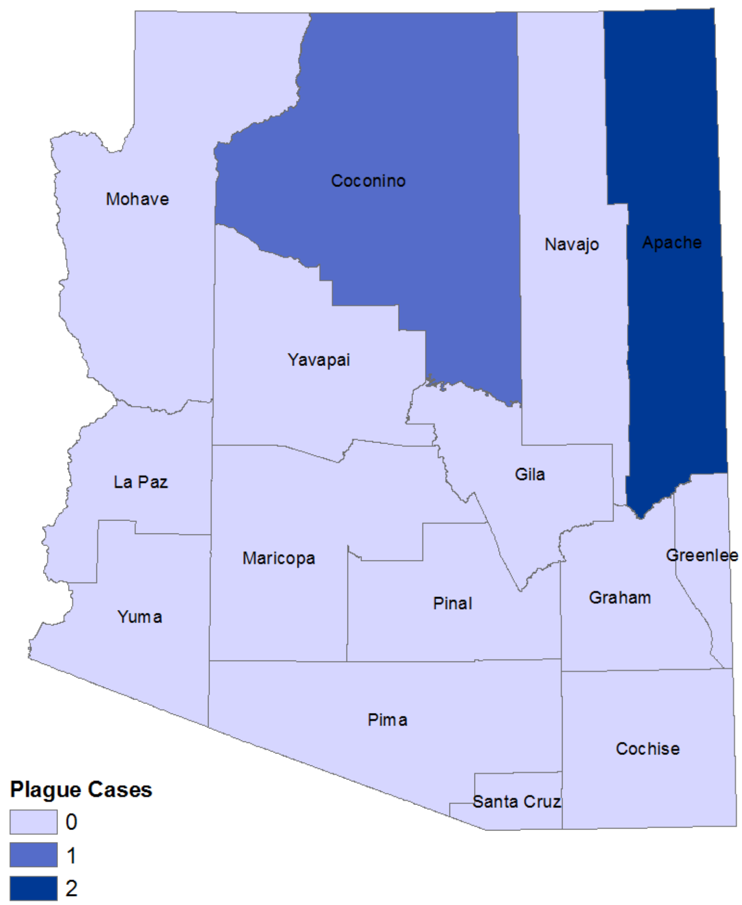


Figure 6. Total number of plague cases (by count) in Arizona counties from 2001-2014. Data Source: ADHS Notifiable Diseases, 2001-2014.

Relevance to Climate: Quantifying how climate drives human plague dynamics is challenging because of the complexity of the transmission cycle involving multiple hosts and multiple flea species and the infrequency of human cases. Generally, a wetter and warmer climate (though not a hot one) results in increased plague activity among reservoir and susceptible rodent hosts. This increased activity, in turn, results in a greater risk of disease for humans. However, the variability among studies is indicative of the challenges of modeling this system and predicting how it will change in the US, due to divergence based on location, species specific differences, and limited human disease data.

Using 56 years of human plague cases in the US, Ben Ari et al. (2008) showed warmer and wetter years tended to coincide with years that had increased human cases. However, because human cases are rare, in the US, much of the incidence for an association between climate and plague comes from wild and domesticated animal data. The strength and direction of the associations vary by geographic region and primary reservoir. For example, Coolinge et al. (2005) found that the warmth of the current year and the amount of water of the previous year were significantly associated with plague among prairie dogs in Montana but not in Colorado.

Plague provides a reminder of the significance of temperature thresholds with respect to the general warming temperature –increasing disease risk. Both Brown et al. (2010) and Coolinge et al. (2005) found an upper threshold where hot days had a negative effect on the incidence of plague. This temperature threshold has been reported in the literature for decades, suggesting temperatures above 27°C halt plague transmission (Davis, 1953; Cavanaugh and Marshall, 1972) though its mechanism is not well understood.

Image 3. Field rodents, such as prairie dogs and ground squirrels, are susceptible to infection with the causal agent of plague, Yersinia pestis. Source: **http://phil.cdc.gov/phil/details.asp**. Photo Credit: CDC.

Hantavirus Pulmonary Syndrome (HPS) results from infection by hantaviruses, which are single-stranded RNA viruses transmitted to humans by rodents via contact with urine, droppings, and saliva (Gubler et al. 2001). Initial symptoms of HPS include fatigue, muscle aches, fever, and dizziness, but may progress to severe coughing and shortness of breath (Kolivras and Comrie, 2004).

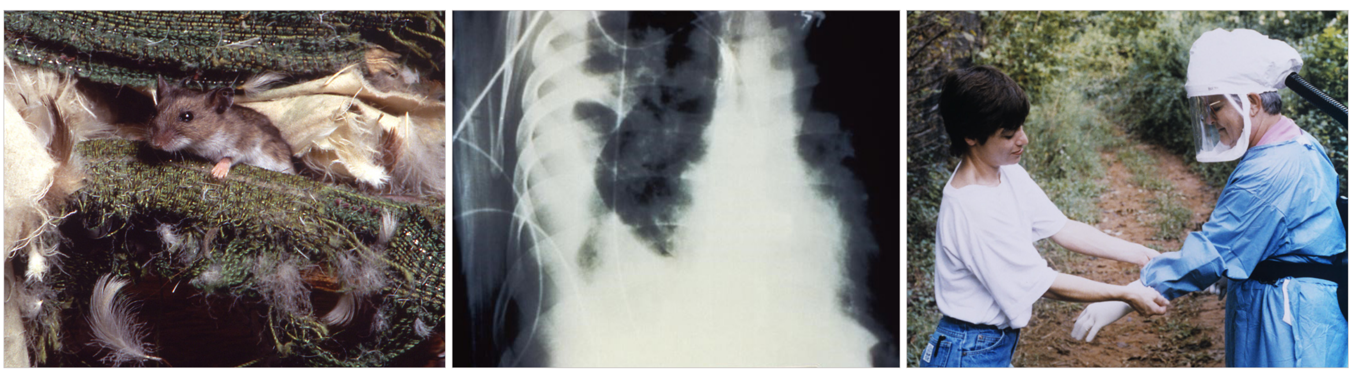


Image 4. The image to the far left is of a deer mouse, Peromyscus maniculatus, which is the principal reservoir for Sin Nombre virus—the primary virus for HPS in North America. The middle image is a chest x-ray revealing a large pulmonary effusion due to HPS. The rightmost image depicts a CDC health official donning a containment suit, which filters air and prevents direct contact with the pathogen, in preparation to collect data during a hantavirus outbreak. Photo Credits: **http://phil.cdc.gov/phil/details.asp**, D. Loren Ketai.

While hantaviruses are known worldwide, a novel hantavirus, Sin Nombre virus, was recognized in the Four Corners region of the US in 1993. Greater than 95% of reported cases of Sin Nombre are seen in states west of the Mississippi River, with California, Arizona, New Mexico, and Colorado having more than 50 cases in 2013 (CDC 2016). Of the fifteen counties in Arizona, the highest incidence of HPS was in Apache County (2 per 100,000 population or 21 cases total) between 2001 and 2014 (ADHS Summary of Notifiable Diseases 2001-2014; Figure 7).

Relevance to Climate: Spatially, HPS is primarily restricted to higher elevations and highly associated with the North American deer mouse, *Peromyscus maniculatus* (Kolivras and Comrie, 2004; Glass et al. 2002). HPS outbreaks have followed periods of increased rainfall, which results in increased food availability, thus aiding rodent population growth (Parmenter et al. 1999; Engelthaler et al. 1999). Most human HPS cases are associated with indoor exposures when, after a weather driven population boon, infected rodents enter human dwellings to avoid harsh weather (Gubler et al. 2001).

Total Number of Hantavirus Pulmonary Syndrome Cases by County 2001-2014

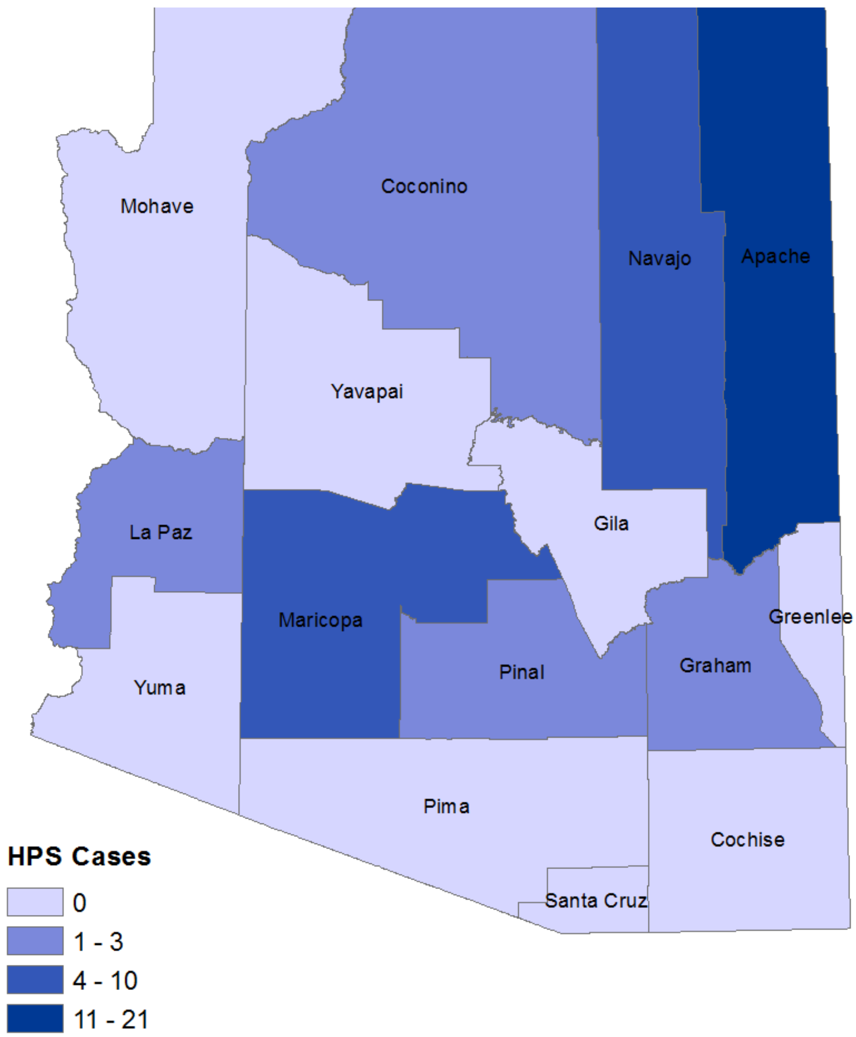


Figure 7. Reported number of HPS cases in Arizona counties from 2001-2014. Data Source: ADHS Notifiable Diseases, 2001-2014.

Coccidioidomycosis, also known as valley fever, is a fungal disease endemic to the Southwest US (CDC 2015). Infection occurs when the fungal spores (arthroconidia) of *Coccidioides* species are inhaled (CDC 2015; Kolivras and Comrie 2001; Galgiani et al. 2000). Common symptoms of coccidioidomycosis include fever, difficulty breathing, coughing, or acute or subacute pneumonic illness (Petersen et al. 2004; Galgiani et al. 2000). Approximately five to ten percent of valley fever infections result in residual pulmonary sequelae and 0.5-1.0 percent can lead to chronic pulmonary or extrapulmonary infection (Galgiani et al. 2000). Symptoms in most patients with early infection will subside without antifungal therapy. However, when the disease has progressed to pulmonary diseases, long-term antifungal therapy is required (Galgiani et al. 2000).

Reported Cases of Valley Fever per 100,000 People in Arizona from 1990 to 2013

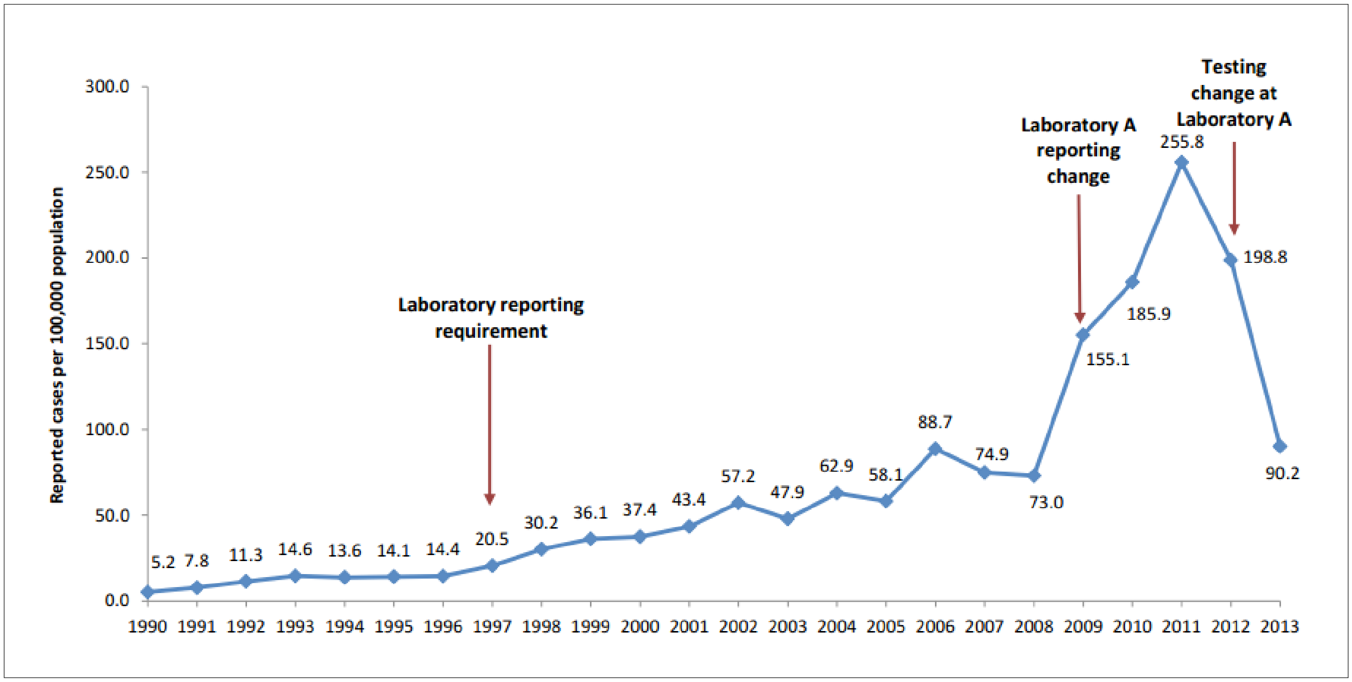


Figure 8. Reported cases of valley fever per 100,000 people in Arizona from 1990 to 2013. Source: 2013 Valley Fever Annual Report.

Fine scale investigations to delineate the environmental risk for exposure to *Coccidioides* spores are limited by the lack of a feasible method for quickly isolating the fungus from soil (Barker et al. 2012). Thus, focal outbreak studies have been used to describe environmental risk. These studies indicated an association with desert landscapes. For example, a recent point-source outbreak among archeologists in Dinosaur National Monument showed that workers performing activities that disturbed the soil were at risk of Valley fever (Petersen et al. 2004).

Incidence of Valley Fever per 100,000 by County, 2001-2014

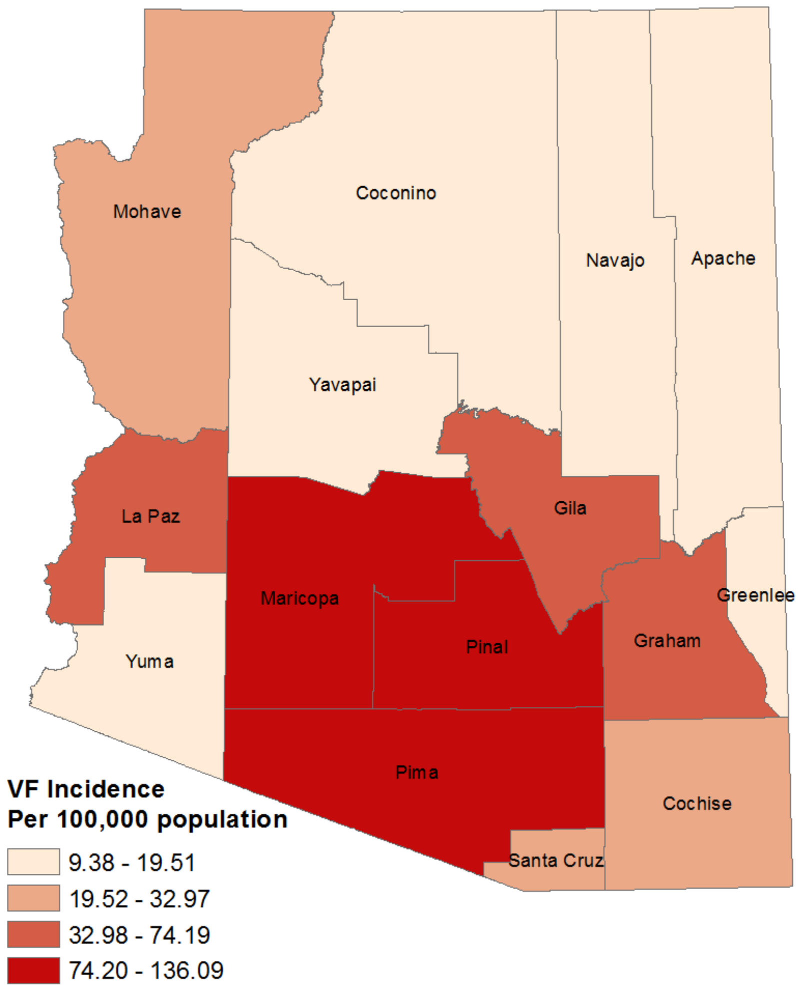


Figure 9. Incidence of Valley fever per 100,000 people in Arizona from 2001 to 2014. Data Source: ADHS Notifiable Diseases, 2001-2014.

In the US, most infections are reported from the endemic regions of southern Arizona, central California, southern New Mexico, and western Texas (Galgiani et al. 2000). Approximately two out of every three cases Valley fever reported in the US are from Arizona residents, with 96 percent of these cases in Maricopa, Pima, and Pinal counties (Arizona Department of Health Services 2013b). Since 2003, the incidence of Valley fever has nearly doubled—from 47.9 cases per 100,000 persons to 90.2 cases per 100,000 persons in the year 2013 (Arizona Department of Health Services 2013a; Figure 8). This change is particularly evident among those aged 65 years and older: from 2000 to 2006, coccidioidomycosis incidence among the elderly more than doubled, from 83 cases per 100,000 persons to 206 cases per 100,000 persons (Sunenshine et al. 2007). These trends are only partly explained by change in laboratory reporting, such as a mandatory reporting requirement that began in 1997 and changes to the case definition in 2009 and 2012.

Using data for the years 2001-2014 in Arizona, the counties with highest incidence of Valley fever were Maricopa, Pinal, and Pima (Figure 9). The incidence rate in Maricopa County was 136.1 cases per 100,000 persons; in Pinal County, the rate was 112.7 cases per 100,000 persons (ADHS Summary of Notifiable Diseases, 2001-2014). In Pima County, the incidence rate of Valley fever was 98.3 cases per 100,000 persons (ADHS Summary of Notifiable Diseases, 2001-2014).

Relevance to Climate: The evidence to support the association among weather, climate, and Valley fever incidence is challenging and depends on the data used and the location studied. Under the *Grow and Blow* hypothesis, precipitation during the fall leads to fungal growth and subsequent drying during the fall and winter of the next year, which allows the spores to form and then spread. A study using data from Pima County, Arizona, showed a strong association between monthly Valley fever incidence and

Image 5. This photograph depicts a dorsal view of a female Rocky Mountain wood tick, *Dermacentor andersoni*. This tick specie is a known North American vector of *Rickettsia rickettsii*, which is the etiologic agent of Rocky Mountain spotted fever. Source: **https://phil.cdc.gov/phil/details.asp**. Photo Credit: CDC.

precipitation during the normally arid spring/early summer 1.5–2 years prior (Comrie 2005). Similarly, in Maricopa County, Arizona, drought indices, wind, temperature, precipitation, and the concentration of particulate matter smaller than 10µm were significant predictors of the monthly variation in incidence (Park et al. 2005). However, in Kern County, California, previous number of cases, not climate or weather, was the primary driver of weekly Valley fever incidence (Talamantes et al. 2007). Differences observed by study area may be partially explained by the timing of the summer monsoons (Zender and Talamantes 2006).

Challenges associated with a lack of good tools to isolate the fungus from the soil, as well as changes in reporting practice, will continue to complicate discernment of the association between climate and Valley fever incidence.

Rocky Mountain spotted fever (RMSF) is a tick-borne disease transmitted in Arizona primarily by *Rhipicephalus sanguineus*, the brown dog tick, and by *Dermacentor* ticks in other regions of the US. Symptoms of RMSF occur within the first two weeks of a tick bite, with non-specific symptoms such as fever, headache, nausea, muscle pain, and rash. Doxycycline should be used to treat both adults and children within the first five days of infection (CDC 2013b). Although progression of disease varies, the infection may require intravenous antibiotics with prolonged hospitalization or intensive care (CDC 2013b). Although Arizona has recently seen increases in the number of reported RMSF cases, the case fatality rate for this vector-borne disease has declined from 28 percent in 1944 to less than 0.5 percent by 2010 (CDC 2013b).

Image 6. The association of *R. sanguineus* with dogs is evidenced by the abundance of ticks on this dog's ear. During a RMSF campaign, CDC and ADHS staff provided community education and flea collars for dogs. Photo credit: N. Drexler.

Total Number of Cases by County 2001-2014

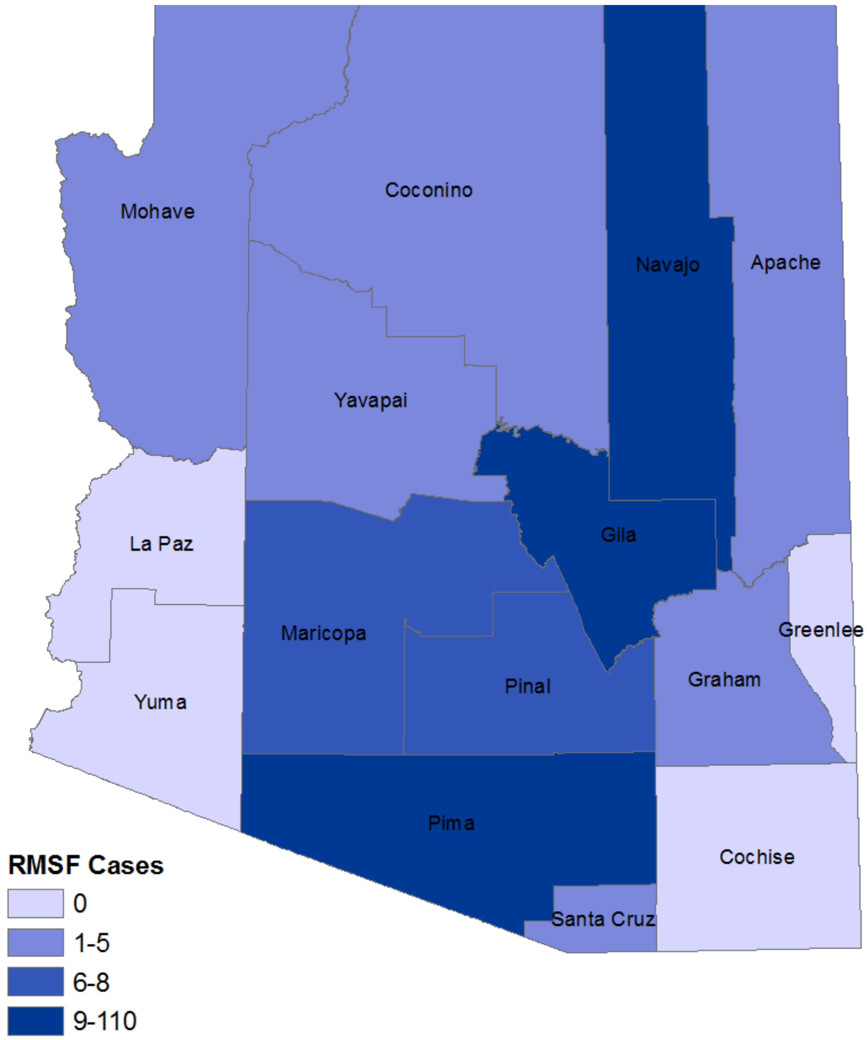


Figure 10. Reported Cases of Rocky Mountain spotted fever in Arizona from 2001 to 2014. Data Source: ADHS Notifiable Diseases, 2001-2014.

RMSF was uncommon in Arizona prior to 2001, but recent years have seen increasing incidence rates, especially in eastern Arizona (ADHS Summary of Notifiable Diseases 2001-2014; Demma et al. 2015). Gila County has the highest incidence rates for RMSF in Arizona, with 11.3 cases per 100,000 persons, followed by Navajo County with an incidence rate of 7.3 cases per 100,000 persons (ADHS Summary of Notifiable Diseases 2001-2014; Figure 10). Incidence rates among other counties in Arizona are low. For example, the incidence rate of RMSF in Graham County was 1.0 cases per 100,000 persons in the same period. In Maricopa County, the most populated Arizona county, the incidence rate was 0.02 cases per 100,000 persons.

Relevance to Climate: Unlike other ticks, *R. sanguineus* is strongly adapted to live in human habitations and can often be found inside homes (Dantas-Torres 2010). The life cycle of this peri-domestic tick makes it challenging to link its abundance and behavior to climate and climate projections. However, a seasonal pattern exists, with the incidence peaking in July through September in Arizona, which is later than other US regions (Traeger et al. 2015).

Vulnerable Populations

Climate is not an "equal opportunity" hazard; rather, it can affect specific populations and demographic groups in different ways, depending on the financial, technical, and social resources available to each group that would allow them to help cope with climate impacts. Multiple studies have shown that a "climate gap" affects low-income populations, minority populations, the elderly, and young children (Shonkoff et al. 2011). In Arizona, almost one out of every five people lives in poverty. The population of Arizona consists of greater than thirty percent Hispanic and approximately five percent American Indian. Although the national poverty rate is less than fifteen percent, 36 percent of American Indians and 27 percent of Hispanics in Arizona live in poverty (**www.census.gov**).

trying to cross the desert (Arizona Department of Health Services 2012). Extreme heat may indirectly contribute to some health conditions by encouraging people to stay indoors rather than being active outside (Wilder et al. 2016). People who are considered to be low-income are more likely to live in rental housing or mobile homes, and are more likely to lack sufficient cooling (and heating) or the resources to use them sufficiently. Low-income and minority populations are often concentrated in urban neighborhoods that lack trees, parks, and green space (Harlan et al. 2013). Gender is a significant dimension of climate vulnerability. In Arizona, 38 percent of female-headed households with children under eighteen years old are below the poverty line, as compared to the 11.2 percent of married couples that fall below the poverty line (US Census 2012).

It is important to understand and communicate clearly that "age, gender, and ethnicity are not in themselves indicators of social vulnerability to climate; however, when linked with low-income status, some age or ethnic groups have been shown to be disproportionately at greater risk of negative climate-related impacts" (Wilder et al. 2016). Some ethnic groups may also have traditions of living in multi-generational households or have well-functioning social networks that are important ingredients to being more climate-resilient as a community.

Arizona is close to the national average in terms of elderly population (over 65 years old), at approximately thirteen percent. However, the aging population is rapidly growing in size and diversity. The number of Arizonans over age 85 is expected to increase by 102 percent between 2000 and 2020. Between 1995 and 2025, the growth of Hispanic persons aged 65-84 years (59 percent) is estimated to far outpace the growth of White non-Hispanics in this same age group (sixteen percent) (Office of the Governor 2005). Compared to the national average, Arizona has a higher percentage of children living in poverty and children who lacked food security. Overall, Arizona faces challenges for improving children's well-being (KidsCount 2013).

How do these statistics relate to how people experience climate in Arizona? Climate-related health disparities among low-income populations are well documented (see, for example, Brown et al. 2013). Climate conditions, such as extreme heat, have been shown to severely affect vulnerable populations in Arizona. Between 2000 and 2012, 1,535 people died due to heat exposure, including elderly residents and visitors, homeless people, and undocumented migrants

In a recent study conducted in southern Arizona, Wilder et al. (2016) found that low-income elderly people and minority communities have to balance multiple challenges, including those posed by climate extremes, to ensure their daily survival. Trading off paying for air conditioning in summer (heating in winter), buying food, paying the rent, and affording health care is a common occurrence for people of low-income here. People living at the economic margin may tend to slip out of the safety nets of social programs and government assistance if their swamp cooler breaks down or Meals-on-Wheels assistance gets reduced. Undocumented (and mixed status) immigrant families were found to be particularly at-risk of suffering from climate impacts, especially heat, as they often avoid going out in public and may prefer not to seek out available social services (such as energy assistance or food programs). On a positive note, across southern Arizona, communities and neighborhoods are mobilizing to be more climate-prepared through programs such as urban shade tree plantings and community gardens.

Social Vulnerability Indicators

Image 7. CDC's Rocky Mountain spotted fever (RMSF) project is combining homeowner education, pesticide application and dog population control to reduce transmitting RMSF to humans in a small community of a tribal reservation in Arizona. Photo credit: Craig Manning/CDC

Spatial identification of infectious disease vulnerability for population groups is made possible through geospatial research and the production of maps identifying geographies that contain vulnerable populations. Geographic information systems (GIS) software is one tool in which data overlay, analysis, and display can be used to conduct vulnerability analyses. Meaningful representations of vulnerable populations are based on measurements, calculations, and models that produce visual representations of select vulnerability metrics. In addition, these methods allow analysts to identify areas that are considered to be high, moderate, and low-risk based on the underlying hazard source.

Mapping vulnerability, an increasingly popular technique to validate and triangulate data, allowing for the derivation of more robust measures to guide both policy analysis and intervention strategies. This form of mapping generally involves the process of spatially mapping indicators in order to compare the dynamics and spatial distribution of individual variables of concern, as well as the interactions that occur between them (Adger 2006). Adding a spatial component to vulnerability analysis allows a location to become more than a passive geographic container: instead, it becomes an active dimension in social relations (Masuda and Garvin 2006). Local social and cultural geographies are increasingly being recognized as a means to examine vulnerability. In this respect, social vulnerability is a reference to more than socio-economic impacts as it can also entail physical characteristics of the built environment or natural landscape.

Cutter et al. (2003) notes that "generally speaking, vulnerability to environmental hazards means the potential for loss," (p. 242) and outlines the three most common areas of vulnerability research. These areas of research include (1) exposure models that focus on identifying conditions that render people or places vulnerable to natural hazards and disasters; (2) human vulnerability as a social condition that measures the resilience of a society in the face of calamity; and (3) an integration of both potential exposures and societal resilience that focus on a particular geographic location or region. It is their assertion that much of the current vulnerability research focuses on individual characteristics of the people that comprise the study area's population and do not focus on place inequalities. Therefore Cutter et al. (2003) developed the Social Vulnerability Index (SoVI) model to identify geographies of social vulnerability to environmental hazards based on the characteristics of individuals, as well as places in which these individuals reside. They developed a model of social vulnerability as a multi-dimensional concept that allows researchers to identify the characteristics and experiences of communities and individuals that enable them to respond to and recover from environmental hazards.

The SoVI model created by Cutter et al. (2003) was originally developed to analyze the social vulnerability at the county level across the United States, based on data from the 1990 Decennial Census. As part of the initial identification, it can capture the spatial and social differentiation of vulnerability and local conditions that affect the capacity of communities to adapt to environmental hazards. A literature review of social characteristics that contribute to social vulnerability were identified and used as 32 normalized independent variables (Supplemental Table 1). After running a Principal Components Analysis (PCA), eleven of the original 32 components were shown to explain 76.4 percent of the variance. Components were then given positive values if they added to vulnerability and negative values if they mitigated vulnerability. They were summed together with equal weights to create the final vulnerability index. Corresponding index values were mapped by county with all counties aggregated into a single map of the United States. Counties were shaded in gradients of color, based on standard deviation values, to allow for analysis and identification of spatial patterns of social vulnerability within the US at the county level. Mapping of index scores can also be used to quantify and analyze variations in the relative levels of social vulnerability across more localized geographies. In 2010, researchers revisited the formulation of the social vulnerability metrics. Based on new directions in the theory and practice of vulnerability science (which had begun to focus on the constraints of family structure, language barriers, vehicle availability, medical disabilities, and healthcare access), along with the introduction of the US Census Bureau's five-year American Community Survey (ACS) estimates (US Census, 2010), researchers decided to include factors related to these themes in their updated social vulnerability index 2006-10 study (Supplemental Table 2).

Methods

For this analysis, the project team decided that the data used would be gathered from the US Census Bureau's 2010 Decennial Census and the 2009-2013 American Community Survey (Census 2013) five-year estimates. It was also determined that for this statewide study, the spatial unit of analysis would be at the census block level, which is unique to previous social vulnerability index methods and studies conducted in other regions. For data collection methods, normalization, and standardization we followed Cutter's (2011) *The SoVI Recipe*. In deciding to use the smallest unit of analysis that was available from the US Census Bureau, four of the 29 2010 SoVI variables utilized by Cutter et al. (2006) were eliminated because they were either not available at the block level or could not be dis-aggregated down to the block level from a larger unit of analysis, such as the census tract or county level. These excluded variables were QNRES (Percent of Population Living in Nursing and Skilled Nursing Facilities), HOSPTPC (Hospitals Per Capita), QNOHLTH (Percent of Population Without Health Insurance), and QNOAUTO (Percent of Housing Units With No Car), resulting in 25 variables for analysis (Table 1).

Table 1: Variables and descriptions used in state of Arizona Social Vulnerability Index analysis.

Variable	Description
QASIAN	Percent Asian
QBLACK	Percent Black
QHISP	Percent Hispanic
QNATAM	Percent Native American
QAGEDEP	Percent of Population Under 5 Years or 65 and Over
QFAM	Percent of Children Living in Married Couple Families
MEDAGE	Median Age
QSSBEN	Percent of Households Receiving Social Security
QPOVTY	Percent Poverty
QRICH200K	Percent of Households Earning Greater Than $200,000 Annually
PERCAP	Per Capita Income
QESL	Percent Speaking English as a Second Language with Limited English Proficiency
QFEMALE	Percent Female
QFHH	Percent Female Headed Households
QED12LES	Percent With Less Than 12th Grade Education
QCVLUN	Percent in Civilian Unemployment
PPUNIT	People Per Unit
QRENTER	Percent Renters
MHSEVL	Mean Housing Value
MDGRENT	Median Gross Rent
QMOHO	Percent Mobile Homes
QEXTRACT	Percent Employment in Extractive Industries
QSERV	Percent Employment in Service Industry
QFEMLBR	Percent Female Participation In Labor Force
QUNOCCHU	Percent Unoccupied Housing Units

Before running the model on the census block level data in a geospatial model we followed Cutter et al.'s (2003) social vulnerability index method and ran a PCA on our 25 variables at the state level using the SPSS software package which resulted in 11 variables explaining 27.3% of the variance (Supplemental Table 3). Generally, PCA is more valid when the variables account for at least eighty percent of the variance. This "80% rule" is more common on smaller datasets, but even on individual-level data, the expectation is that at least fifty percent of the variance will be explained by the variables. However, by including all factors from the PCA the variance threshold is met.

Using all 25 variables, the project team attempted to first run the social vulnerability model in ESRI's GIS software ArcMap for the entire state at a quarter of an acre resolution (30 meter cell size). The team developed a three step additive model in ArcMap's Model Builder in which each of the variables and it's affiliated percentage values were: (1) converted from a polygon to a raster grid; (2) reclassified into 5 categories based on natural breaks in the histogram with 1 equating to low vulnerability and 5 equating to high vulnerability; and (3) using a weighted sum to add all the reclassified variables to derive a final social vulnerability value for each of the census blocks. It should be noted that within the weighted sum tool there were no weights given to the variables as none of the variables as prescribed by Cutter et al. (2006) were shown to have more of an impact on social vulnerability.

Processing limitations hindered us from analyzing all 241,666 individual Census Blocks in ArcMap in one single model. Thus instead of using all census blocks, calculations of social vulnerability were done on a regional scale. The first region, Southern Arizona, included the Arizona census blocks south of the Gila River. After running the model the resulting map did not visually make sense because areas around the border of Arizona and Mexico and on Native American reservations were showing low vulnerability. We speculate that this was a result of common Census data/count inaccuracies on Tribal lands or alternatively that many of the PCA factors simply did not exist on Tribal lands. To better understand the factors and determine if regional variability provided better results than the statewide analysis, we re-ran the PCA for the Southern Arizona region within GIS and the model indicated that 7 variables explained 13.1% of the variance (Supplemental Table 4). We re-ran the model using only the 7 variables identified in the PCA and in addition to the low variance, still resulted in the map appearing inaccurate. After attempting at multiple spatial scales to reduce the number of observed variables into a smaller number of components, the project team concluded that the determination of variability should include all 25 variables for the entire state. It was also determined by the team that because of the aforementioned processing limitations in of running the model on the entire state and the challenge of matching up jurisdictional boundaries such as census blocks with that of a natural landscape feature – the Gila River in the southwest region analysis – that the state would be split into the fifteen counties for analysis with subsequent aggregation into a final map post analysis. We used the clip tool to clip out the census blocks contained within each county, ran the individual county census blocks through our additive model, and finally used the mosaic tool to join all the resulting final files from the counties to create a social vulnerability file for the state of Arizona.

Social Vulnerability Based Model

Areas of high vulnerability (red) were located across the state (Figure 11). Although Arizona demonstrates many physical and socioeconomic differences regionally, and county-specific trends of vulnerability cannot be generalized, some high variability of vulnerability trends can be seen in the more densely populated regions of Tribal lands, near farmlands, in pockets in and around urban areas, and on lands adjacent to large expanses of the natural environment.

Environmental Hazard Indicators

In addition to the underlying social vulnerability that a community may experience, there are characteristics that create additional vulnerability, which may influence risks of disease. The causal pathway illustrates the steps between an exposure, its modifiers, to the health impacts. The environmental exposures can be the environment where a pathogen grows, or mosquitoes live and breed. Modifiers are factors that influence a population's likelihood of being exposed or becoming ill. The pathway ends with the associated health response. Working through a causal pathway serves to identify critical factors that need to be understood and incorporated into an explicit model of the disease. The causal pathway can be important for both Step 1 (the vulnerability assessment) and Step 2 (projecting disease burden) of the BRACE framework. In each application, they serve to explicitly delineate key factors important to the disease in question.

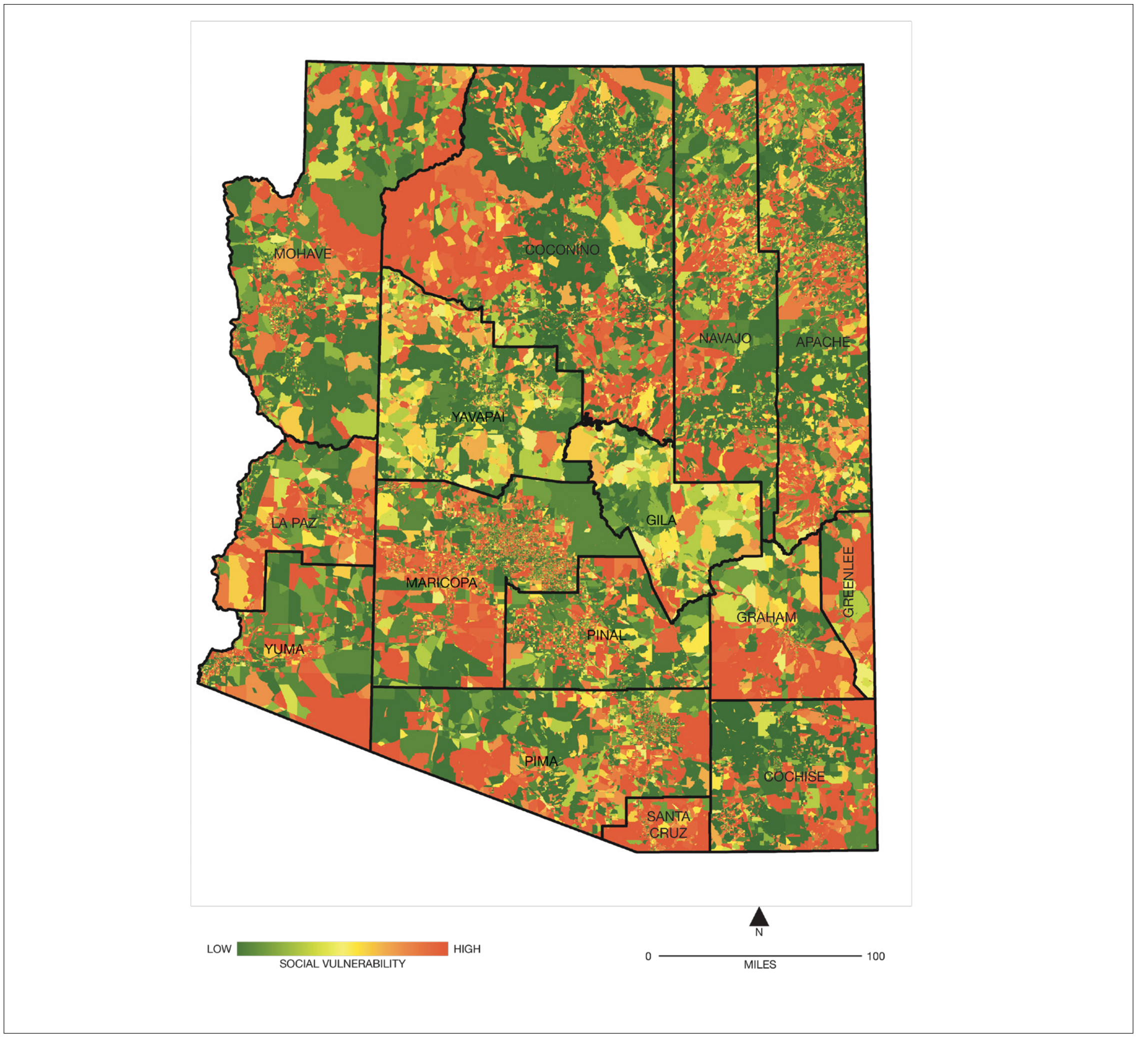


Figure 11. Arizona Social Vulnerability Index, by Census Block.

The factors that were used to generate the disease-specific vulnerability (Figures 12 and 13) include those identified based on those causal pathways for which a spatially explicit measurement or proxy could be identified. Both the West Nile virus and Valley fever environmental hazard indicators were individually added to the social vulnerability base model. A binary classification was used such that areas possessing the criteria identified in the causal pathway had a weighting of 5 added to their social vulnerability value and those without the criteria were not weighted. This additional analysis resulted in two additional maps showing social vulnerability plus the causal pathway accounting for each health risk.

West Nile Virus Disease: Beyond the social vulnerabilities influencing a community's capacity to adapt or respond to climate change, two factors modify WNV disease vulnerability: an individual's susceptibility to infection and physical capacity to withstand the disease, and the factors that influence the distribution and abundance of mosquitoes capable of transmitting WNV.

In the case of West Nile virus, the environmental exposure results from a bite from an infectious mosquito. Modifiers in this causal pathway are factors that increase the likelihood of human disease and can include both intrinsic factors, such as individual susceptibilities, or extrinsic factors, which are related to risk of exposure. For West Nile virus disease, the elderly population is at greater risk of neuroinvasive disease due to weakened immune systems (Ampel et al. 1998; Sunenshine et al. 2007). Environmental modifiers include proximity to mosquito breeding habitats, where populations closest to favorable breeding habitats may be at greater risk for exposure. While other factors, such as immune status and human behavior (e.g., doning protective clothing, fogging, or source reduction) may influence risk, there are no spatially explicit data available for these factors.

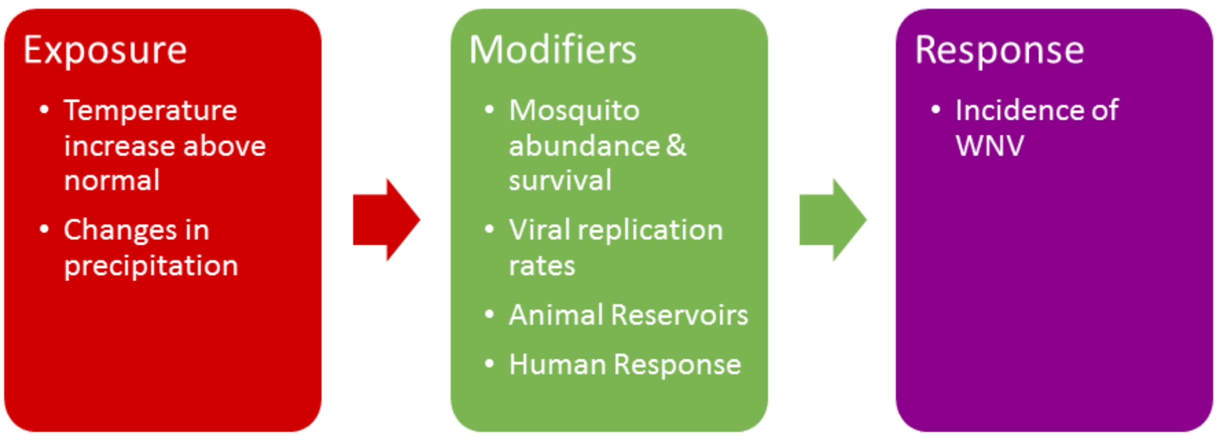
The Elderly are particularly susceptible to severe neurological disease and death from WNV. The innate immune response to WNV is altered with aging, suggesting a mechanism for the observed increased severity of WNV infection (Kong et al. 2008).

The growth in Arizona's aging population may indicate an increased at-risk population for WNV. Age related vulnerability is already incorporated into the social vulnerability model.

Availability of vector habitat adds an additional layer of risk for WNV, both from the likelihood that mosquitoes will be present and from those factors that increase their abundance. Three characteristics were identified: urbanization (important for *Cx. quinquefasciatus*), distance to agriculture (important breeding habitat for *Culex tarsalis*), and neglected swimming pools (a key habitat for additional risk within urban areas).

In Arizona, *Cx. quinquefasciatus* and *Cx. tarsalis* are the primary WNV vectors, with the former species being associated with urban areas. Within urban areas, studies in California have found significant associations between neglected pools and cases of West Nile virus (Reisen et al. 2008b; Harrigan et al. 2010). We include neglected swimming pools in our model of WNV vulnerability.

National Agriculture Imagery Program (NAIP) imagery (courtesy of the US Geological Survey) from the summer of 2010 was joined, into multiband raster images. This imagery was more effective than Landsat for identifying pools because of the higher 10 meter resolution, rather than 30 meter resolution. To identify algal blooms in swimming pools, we first inspected NAIP imagery to find samples of swimming pools with and without such blooms. NAIP imagery has bands for red, green, blue, and near-infrared (NIR) light. Value samples were taken from each band by three classes of the landscape: pools with algae, pools without algae, and the landscape surrounding pools. These value samples were compared by class and band to identify which bands showed the most unique values in the pools with algae. Near-infrared and green bands were shown to have the most unique values to this class. A Normalized Difference Water Index (NDWI) was calculated using the reflectance in the green and near infrared wavelengths:



Causal pathway for vector-borne disease vulnerability: Mosquito vector, WNV. This pathway limited to those variables for which spatially explicit information is available.

NDWI: (GREEN – Near Infrared)/(GREEN + Near Infrared).

NDWI gives a series of values ranging from -1 to 1, which is a measure of the liquid water content of vegetation (Gao 1996). For this index, negative values tend to indicate water, while positive values indicate increasing vegetation (McFeeters 1996). An unsupervised inspection of NDWI values by class showed a range of values from 0.02 to 0.07 as a classification of algae reflectance versus other water and the surrounding landscape and plant life. The NDWI was reclassified into two values: potential algal blooms and other. The data was further constricted spatially by masking the extent to only include private properties and developed areas, which resulted in the exclusion of agricultural lands and other areas where water might collect. Counties in the Colorado Plateau (Coconino, Navajo, and Apache counties) were excluded from the analysis due to reduced number of swimming pools and the higher prevalence of other sources of potential error. The remaining algal blooms were converted to points and every census block that intersected algal blooms was converted to a raster using a binary classification where values of 5 represent the presence of algal blooms and values of 0 represent no algal blooms.

West Nile Virus Specific Social Vulnerability: As with the base map (Figure 11), this census block level analysis shows high variability with some pockets of increased vulnerability (Figure 12). Among those counties in the Colorado Plateau where the WNV modifiers we identified were not mapped, there is limited incidence of WNV (Figure 5). In Graham County, the high social vulnerability (Figure 11 and 12) is coincident in the incidence rates calculated using the last fourteen years of data (Figure 5). Figure 13 provides a difference map between the base (Figure 11) and the disease specific (Figure 12) maps, highlighting the areas identified to be those with the modifiers associated with WNV risk.

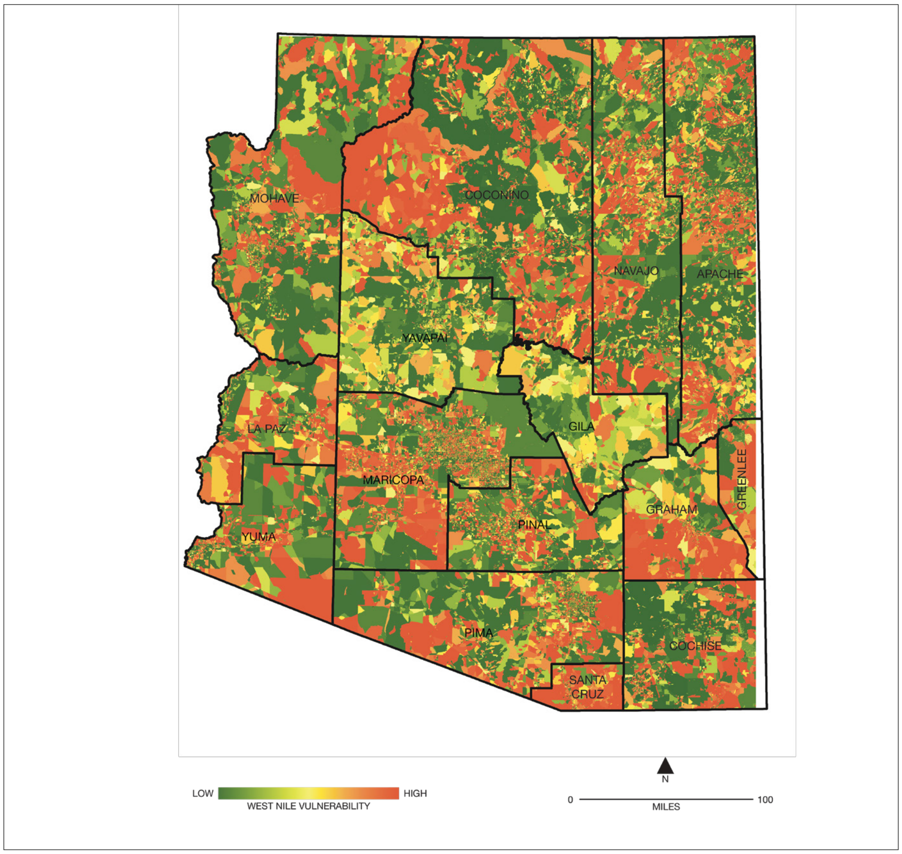


Figure 12: Arizona West Nile Virus Vulnerability by Census Block.

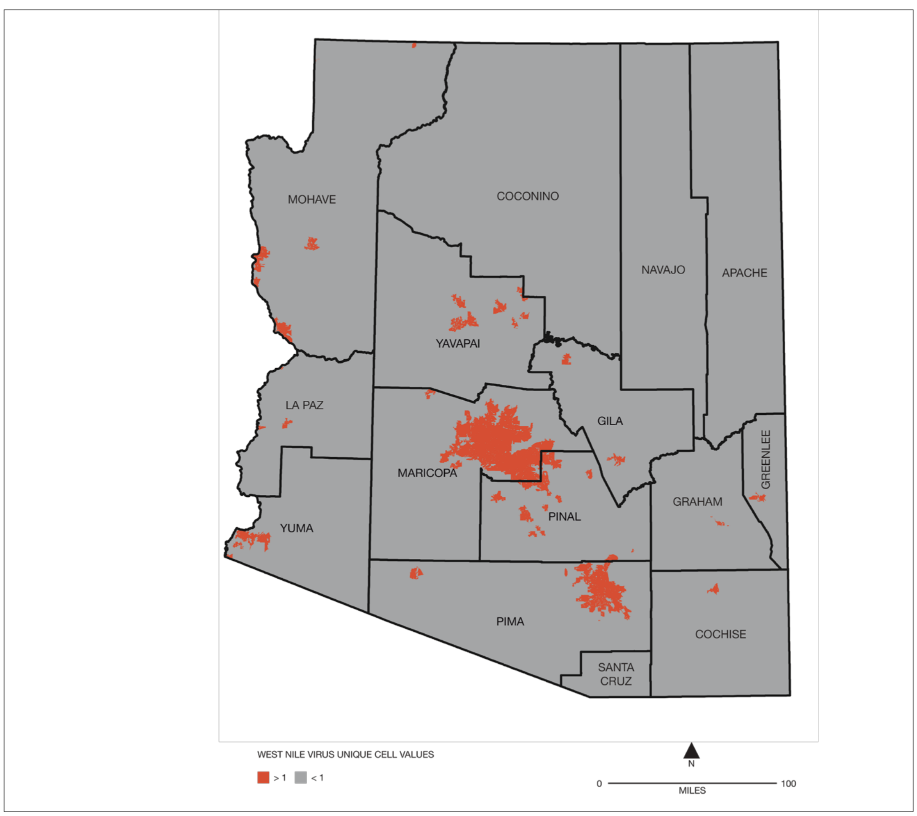
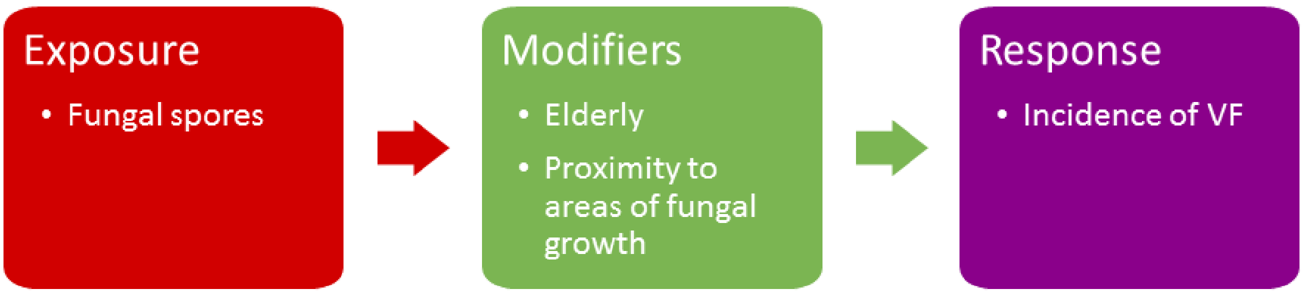


Figure 13: Differences in vulnerability values between the base model (Fig. 11) and the West Nile Virus modified social vulnerability. The areas with unique cell values greater than 1 indicate a difference in the vulnerability value of the model and the other respective vulnerability index map.



Causal pathway for Valley fever vulnerability: This pathway limited to those variables for which spatially explicit information is available.

Valley Fever: Similar to WNV disease, there are both biological and environmental factors that put an individual at greater risk for being exposed to and contracting Valley fever. Again, individuals with weakened immune systems generally have modified risk of disease incidence. Furthermore, those in close proximity to and/or have repeated exposure to soil that contains fungal spores are at greater risk for incidence of Valley fever. Previous exposure may be protective.

Elderly individuals are at greater risk for developing symptomatic Valley fever. According to the CDC Morbidity and Mortality Weekly Report in 2011, the incidence of Valley fever in Arizona for ages 40-59 was 335.1 cases per 100,000 persons, whereas for 60-79 year olds, the incidence was 381.1 cases per 100,000 persons. The incidence for ages greater than or equal to 80 years old was 254.0 cases per 100,000 persons (CDC, 2013a). While this population experiences increased risk, they are already included in the social vulnerability analysis (Figure 11).

Activity in areas where fungus grows is associated valley fever incidence due to the aforementioned challenge of recovering the fungus from the soil, which creates a challenge to explicitly delineate areas where the fungus grows. However, case studies show that activities involving aerosolizing of soil in previously undisturbed areas may lead to increased risk. In a study of urban Maricopa County, Park et al. (1995) found that areas with high rates of construction had higher age-adjusted rates of disease; however, they did not find an association with building permit issuance.

Similarly, outbreaks occurred among a team of archeologists in Utah (Petersen et al. 2004) and among construction workers excavating in California (Cummings et al. 2010). For the valley fever specific vulnerability analysis, a proxy for disturbed land was created by giving a weight of 5 to any pixel from the National Land Cover database (NCLD) that transitioned to agriculture or development between 2006 and 2011 (Jin et al. 2013).

Valley Fever Specific Social Vulnerability: Despite that cases of Valley fever are associated with the more populous regions of the state (Maricopa, Pima and Pinal counties, Figure 9), the vulnerability seems lower in these regions (Figure 14). It may be indicative of the greater capacity for these regions to respond. The mismatch of disease incidence and vulnerability may also indicate the challenge with identifying the appropriate risk factors associated with Valley fever exposure or an issue of spatial resolution where these more populated areas have smaller census blocks and the vulnerability is harder to discern visually. The difference map (Figure 15) shows areas with the identified modifiers, and proximity to fungal habitat.

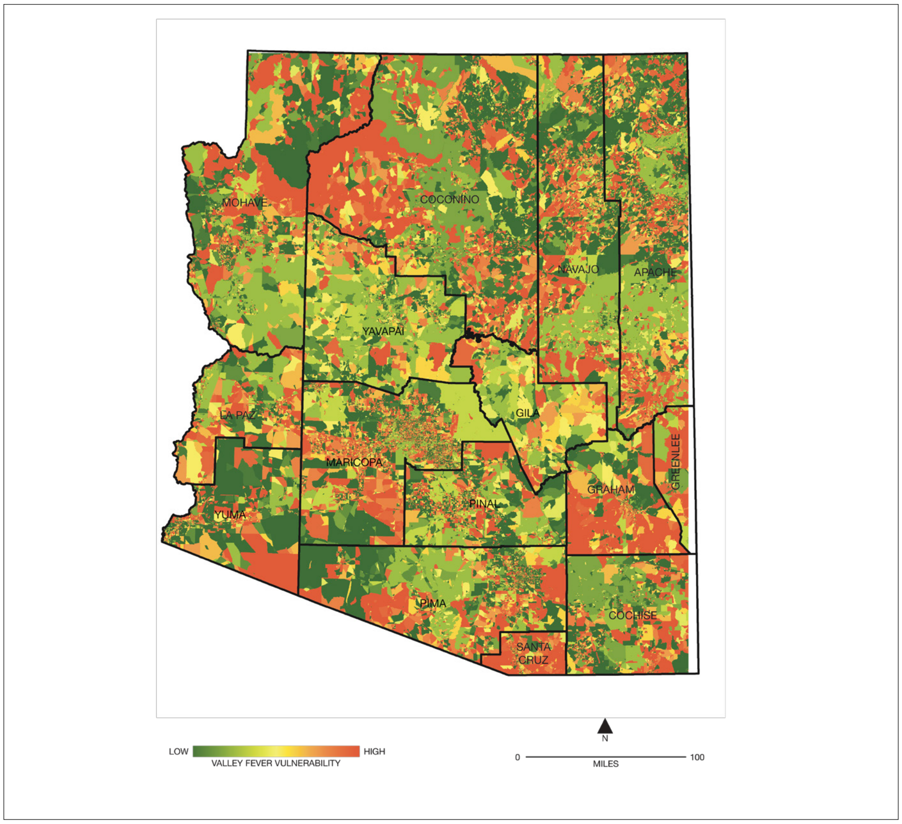


Figure 14. Arizona Valley Fever Vulnerability by Census Block.

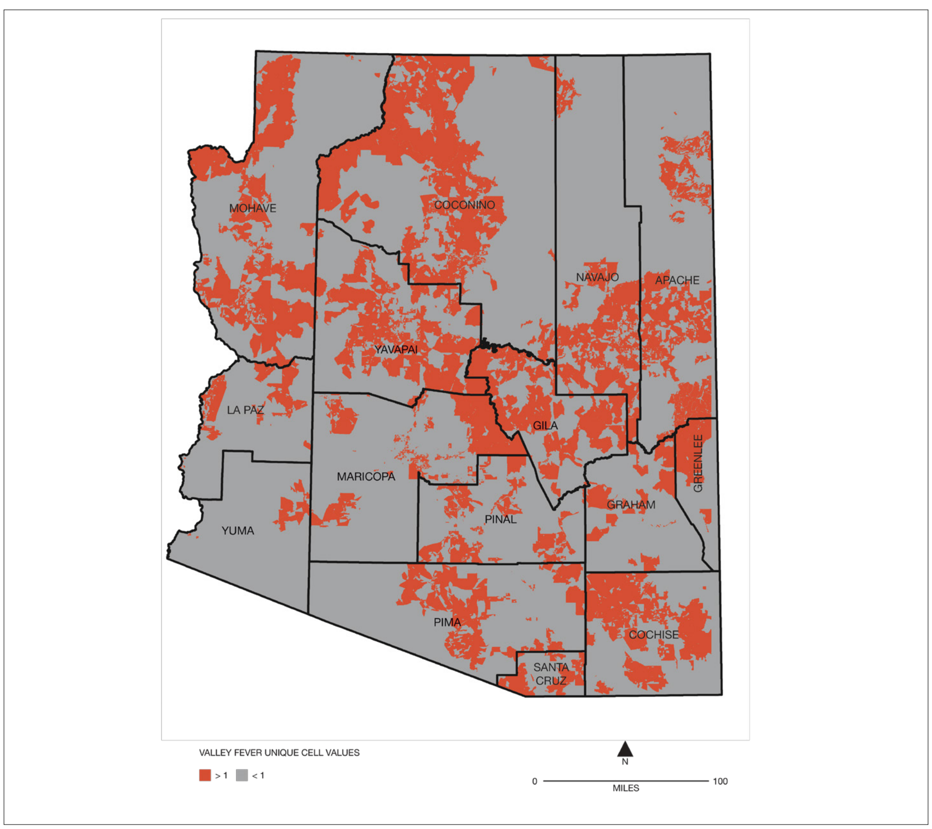


Figure 15: Differences in vulnerability values between the base model (Figure 11) and the valley fever modified social vulnerability (Figure 14). The areas with unique cell values greater than 1 indicate a difference in the vulnerability value of the model and the other respective vulnerability index map.

Limitations

This report presents a vulnerability assessment for Arizona for specific infectious diseases. While a general overview of multiple diseases are provided, West Nile virus disease and Valley fever were selected for further study because of both the burden on Arizona residents as well as the amount of data available to model the association between these disease and climate. The evidence for the association with climate and certain infectious diseases of burden in Arizona, along with updated spatially explicit representations of disease incidence, are provided. A vulnerability assessment using the SoVI methodology was then applied at the census block level for the whole state, resulting in high resolution vulnerability maps both generally and specific to West Nile virus disease and Valley fever.

Many of the limitations have been discussed in each section, but additional limitations (especially with respect to the social vulnerability) are discussed here. Specifically, the very high spatial resolution selected (US Census block) creates uncertainty resulting from missing data or variables with significant margins of error at the block level. By dis-aggregating a nationwide model to the state level there may be some variables that are either not applicable to vulnerability in the state or alternatively are left out of the national model but may have an impact on the statewide vulnerability. There is a significant amount of land in the state that is controlled by Tribal governments and as such using Census data within a spatial model presents additional challenges, as data gathered on Tribal reservations may be collected and maintained differently, creating incomplete datasets when combined with other available data. The proxies that were selected (neglected pools and land use classification change between 2006-2011) are within the causal pathways and reproducible, but they may not be the most valid metric of disease risk. However, on a state-wide scale, other data were not available.

There are certain vulnerable populations for which there are no statewide data available, but which may represent additional populations such as un- or under-counted populations like migrant or transient populations. For Valley fever in particular, these populations may be more susceptible because of a lack of previous exposure.

Conclusions

This report presents a vulnerability assessment for Arizona for specific infectious diseases. While a general overview of multiple diseases are provided, West Nile virus disease and Valley fever were selected for further study because of both the burden on Arizona residents as well as the amount of data available to model the association between these disease and climate. The evidence for the association with climate and certain infectious diseases of burden in Arizona, along with updated spatially explicit representations of disease incidence, are provided. A vulnerability assessment using the SoVI methodology was then applied at the census block level for the whole state, resulting in high resolution vulnerability maps both generally and specific to West Nile virus disease and Valley fever.

The Assessment highlighted two diseases of concern due to their association with climate and their impact on Arizona and the US Southwest-West Nile virus disease and Valley fever. A US Census block level social vulnerability analysis was conducted, showing vulnerability across Arizona to be quite variable.

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Supplemental Materials

Supplemental Table 1: Variables and descriptions used in Cutter et al.'s (2003) 2000 SoVI analysis.

Variable	Description
QASIAN*	Percent Asian
QBLACK*	Percent Black
QSPANISH*	Percent Hispanic
QINDIAN*	Percent Native American
QKIDS	Percent Kids
QPOP65O	Percent of Population Over 65
MEDAGE*	Median Age
QSSBEN	Percent Social Security Beneficiaries
QPOVTY	Percent Poverty
QRICH	Percent of Households Earning Over $100,000 Annually
PERCAP*	Per Capita Income
QMIGRA	Percent of Foreign Born Who Are Recent Migrants
QFEMALE	Percent Female
QFHH	Percent Female Headed Households
NRRESPC	Nursing Home Residents Per Capita
HOSPTPC	Hospitals Per Capita
PHYSION	Number of Physicians Per 10,000 People
QED12LES	Percent With Less Than 12th Grade Education
QCVLBR	Percent in Civilian Labor Force
QCVLUN	Percent in Civilian Unemployment
QURBAN	Percent Urban Population
QRFRM	Percent of Population on Rural Farms
PPUNIT	People Per Unit
QRENTER	Percent Renters
HODENT*	Housing Density
MHSEVL	Mean Housing Value
MCRENT	Mean Contract Rent
QMOHO*	Percent Mobile Homes
QAGRI*	Percent Employment in Extractive Industries
QSERV*	Percent Employment in Service Industry
QTRAIN*	Percent Employment in Transportation and Public Utilities
QFEMLBR	Percent Female Participation In Labor Force

*Variables identified in the PCA that explained 76.4 percent of the variance

Supplemental Table 2: Variables and descriptions used in Cutter et al.'s (2006) 2010 SoVI analysis.

Variable	Description
QASIAN	Percent Asian
QBLACK	Percent Black
QHISP	Percent Hispanic
QNATAM	Percent Native American
QAGEDEP	Percent of Population Under 5 Years or 65 and Over
QFAM	Percent of Children Living in Married Couple Families
MEDAGE	Median Age
QSSBEN	Percent of Households Receiving Social Security
QPOVTY	Percent Poverty
QRICH200K	Percent of Households Earning Greater Than $200,000 Annually
PERCAP	Per Capita Income
QESL	Percent Speaking English as a Second Language with Limited English Proficiency
QFEMALE	Percent Female
QFHH	Percent Female Headed Households
QNRES	Percent of Population Living in Nursing and Skilled Nursing Facilities
HOSPTPC	Hospitals Per Capita
QNOHLTH	Percent of Population Without Health Insurance
QED12LES	Percent With Less Than 12th Grade Education
QCVLUN	Percent in Civilian Unemployment
PPUNIT	People Per Unit
QRENTER	Percent Renters
MHSEVL	Mean Housing Value
MDGRENT	Median Gross Rent
QMOHO	Percent Mobile Homes
QEXTRACT	Percent Employment in Extractive Industries
QSERV	Percent Employment in Service Industry
QFEMLBR	Percent Female Participation In Labor Force
QNOAUTO	Percent of Housing Units With No Car
QUNOCCHU	Percent Unoccupied Housing Units

Supplemental Table 3. Arizona SoVI state PCA variables explaining 27.3% of the variance

Variable	Description
QHISP	Percent Hispanic
QAGEDEP	Percent of Population Under 5 Years or 65 and Over
QFAM	Percent of Children Living in Married Couple Families
QPOVTY	Percent Poverty
QFEMALE	Percent Female
QFHH	Percent Female Headed Households
QED12LES	Percent With Less Than 12th Grade Education
QCVLUN	Percent in Civilian Unemployment
QRENTER	Percent Renters
QUNOCCHU	Percent Unoccupied Housing Units

Supplemental Table 4. Southern Arizona SoVI PCA variables explaining 13.4% of the variance

Variable	Description
QFEMALE	Percent Female
QESL	Percent Speaking English as a Second Language with Limited English Proficiency
MDGRENT	Median Gross Rent
QMOHO	Percent Mobile Homes
QSERV	Percent Employed in Service Industry
QFEMLBR	Percent Female Participation in Labor Force
QUNOCCHU	Percent Unoccupied Housing Units

Supplemental Table 5. SoVI vulnerability ranges by county and for the state

Location	Minimum*	Maximum**	Mean	Standard
Deviation				
Apache County	32	61	38.8	6.2
Cochise County	32	144	38.6	8.6
Coconino County	32	149	39.5	7.6
Gila County	33	57	38.1	4
Graham County	33	61	42.7	6.7
Greenlee County	33	59	41.8	5.6
La Paz County	33	61	40.4	5.6
Maricopa County	33	155	39.3	6.3
Mohave County	33	107	38.4	6
Navajo County	33	107	38.9	6.2
Pima County	33	107	39.1	6.4
Pinal County	33	107	38.3	5.7
Santa Cruz County	33	61	45	5.1
Yavapai County	33	57	37.3	4.2
Yuma County	33	60	40	7.2
Arizona	32	155	39.2	6.5

*Lowest minimum value = 32

** Highest maximum value = 155

Backcover (crop): CDC's Rocky Mountain Spotted Fever (RMSF) project is testing the strategy of combining homeowner education, pesticide application and dog population control to reduce the number of brown dog ticks and the potential for transmitting RMSF to humans in a small community of a tribal reservation in Arizona. photo: Craig Manning/CDC


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