MINNESOTA CLIMATE CHANGE VULNERABILITY ASSESSMENT **2014**

Minnesota
Department of Health

MINNESOTA CLIMATE & HEALTH PROGRAM, ENVIRONMENTAL IMPACTS ANALYSIS UNIT

Minnesota Department of Health
Minnesota Climate & Health Program
Environmental Impacts Analysis Unit

625 Robert Street North
PO Box 64975
St. Paul, MN 55164-0975

651-201-4899

health.mn.gov/climatechange/

October 2014

Contents

Acknowledgements 4
Glossary of Terms and Acronyms 5
I Preface 7
II Introduction 8
III Background: Climate Change and Vulnerability 10
Climate Change in Minnesota 11
Review of Vulnerability Assessments 13
IV Extreme Heat Events 15
Background 15
Extreme Heat in Minnesota 17
Populations Vulnerable to Extreme Heat 20
Composite Extreme Heat Vulnerability 27
Effects of Climate Change on Extreme Heat 29
V Air Pollution 30
Background 30
Air Quality in Minnesota 31
Populations Vulnerable to Poor Air Quality 35
Composite Air Quality Vulnerability 38
Pollen 39
Effects of Climate Change on Air Quality 40
VI Vector-borne Disease 41
Background 41
Vector-borne Disease in Minnesota 42
Populations Vulnerable to Vector-borne Disease 45
Effects of Climate Change on Vector Borne Diseases 46
VII Flooding and Flash Flooding 47
Background 47
Flash Flooding in Minnesota 48
Populations Vulnerable to Flooding 54
Composite Flood Vulnerability 60
Effects of Climate Change on Flash Floods 62
VIII Drought 63
Background 63
Drought in Minnesota 65
Populations Vulnerable to Drought 76
Effects of Climate Change on Drought 77
IX Overall Population Vulnerability and Climate Hazard Risks 78
Composite Climate Hazard Risk Map 79
Composite Population Vulnerability Map 80
X Conclusion 81
Study Limitations 81
Next steps 83
Conclusion 83
XI Appendix A: 84
Final literature review of populations vulnerable to natural hazards and climate change and vulnerability assessments 84
XII Appendix B 89
Master list of indicators (prior to culling) 89
Table Citations 96
XIII. References 97

Acknowledgements

MDH would like to thank the following people for their contribution to this document. MDH could not have undertaken this task without the data and guidance from sister state agencies, experts from other MDH programs, and experienced local public health professionals.

- Don Bishop, MDH, Center for Health Promotion
- Peter Boulay, MN State Climatology Office
- Wendy Brunner, MDH, Asthma Program
- Nancy Carlson, MDH, Office of Emergency Preparedness
- Jose Gonzales, MDH, Office of Minority and Multicultural Health
- Bill Groskreutz, Faribault County/State Community Health Services Advisory Committee
- Matti Gurney, Department of Public Safety, Homeland Security and Emergency Management
- Kitty Hurley, MDH, Environmental Public Health Tracking Program
- Marilyn Jordahl-Larson, Minnesota Department of Transportation, Office of Environmental Stewardship
- Margaret McCourtney, Minnesota Pollution Control Agency, Air Data Analysis
- Cassie McMahon, Minnesota Pollution Control Agency, Air Data Analysis
- Todd Monson, Hennepin County, Human Services and Public Health Department
- Paul Moss, Minnesota Pollution Control Agency, Sustainable Development Program
- David Neitzel, MDH, Infectious Disease Epidemiology, Prevention and Control Division
- Mary Olson Baker, Minnesota Department of Human Services, Aging and Adult Services
- Ann Pierce, Minnesota Department of Natural Resources, Conservation Management and Rare Resources
- Gregory Pratt, Minnesota Pollution Control Agency, Risk Evaluation & Air Modeling
- Chuck Stroebel, MDH, Environmental Public Health Tracking Program
- Jeff Travis, Washington County, Department of Public Health and Environment

Glossary of Terms and Acronyms

ACS American Community Survey

AQI Air Quality Index

ASTHO Association of State and Territorial Health Officials

BRACE Building Resilience Against Climate Effects (CDC framework for Climate and Health Program starting in 2012)

CCVA Climate Change Vulnerability Assessment

CDC Centers for Disease Control and Prevention

COPD Chronic obstructive pulmonary disease

Dew point Measure of water vapor; the temperature to which the air must be cooled at constant pressure for it to become saturated

ED Emergency department

EPA Environmental Protection Agency

EPHT Environmental Public Health Tracking

FEMA Federal Emergency Management Agency

Flash flood Flooding as a result of a 24-hour rainfall events of six inches or greater

Flood Normally dry land is submerged by 1) the overflow of rivers or other water bodies, or 2) the unusual and rapid accumulation or runoff of surface waters

Floodplain An area of low-lying ground adjacent to a river or susceptible to being inundated by water from any source

HA Human Anaplasmosis

Hazard Natural disaster or weather which has the potential to cause damage or harm to persons, property, or ecosystems

Heat advisory Maximum heat index reaches 100° F and/or the maximum temperature reaches 95° F or Heat index A calculation that describes how the air temperature and dew point are perceived the human body

Heat warning Maximum heat index reaches 105° F or greater and a minimum heat index of 75° F or greater for at least 48 hours. A warning may also be issued if heat advisory criteria are expected for 4 days in a row

Impervious surface Surfaces that are impenetrable (do not allow infiltration), such as rooftops, roads, parking lots, and soils that have been compacted by development

MDH Minnesota Department of Health

MPCA Minnesota Pollution Control Agency

MRLC Multi-Resolution Land Characteristics Consortium

NAAQS National Ambient Air Quality Standard

NCDC National Climatic Data Center

NFIP National Flood Insurance Program, managed by FEMA

NLCD National Land Classification Database

NO Nitric oxide

NOx Nitrogen oxides

NOAA National Oceanic and Atmospheric Administration

NWS National Weather Service

PDSI Palmer Drought Severity Index

PM2.5 Particulate matter 2.5 micrometers in diameter and smaller

Risk The probability that a natural disaster or weather event will occur at a particular location; and also the probability that a person or group of persons is located in the path of a hazard

SO2 Sulfur dioxide

STARI Southern tick-associated rash illness

Urban heat island effect A result of reduced vegetation and increased impervious surfaces absorbing the heat from the sun throughout the day and releasing the heat at night when temperatures drop, effectively making these areas warmer than rural or undeveloped areas

VOCs Volatile organic compounds

Vulnerability The characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard or other climate hazard

Vulnerable adult Any person 18 years of age or older who:
(1) is a resident or inpatient of a facility;
(2) receives services at or from a licensed facility required to serve adults;
(3) receives services from a licensed home care provider;
(4) regardless of residence or whether any type of service is received, (4a) possess a physical or mental infirmity or other physical, mental, or emotional dysfunction that impairs the individual's ability to provide adequately for the individual's own care without assistance, including the provision of food, shelter, clothing, health care, or supervision and (4b) because of the dysfunction or infirmity and the need for assistance, the individual has an impaired ability to protect the individual from maltreatment [Minnesota Statute 626.5572];

WNV West Nile Virus

I Preface

The Minnesota Department of Health (MDH) conducted a climate change vulnerability assessment for the state of Minnesota to assess population vulnerabilities by county based on retrospective data for the following climate hazards: extreme heat events, air pollution, vector-borne diseases, flooding and flash flooding, and drought. The assessment included a literature review of populations vulnerable to climate change and methodologies for conducting climate change vulnerability assessments. MDH used geographic information systems (GIS) to display vulnerable populations by county and the occurrence of climate hazards at varying geographic scales across the state.

For three climate hazards, extreme heat events, air pollution and flooding, MDH created county-level composite vulnerability scores. This entailed breaking vulnerable population rates and climate hazards incidents into quartiles, assigning quartiles a value from one to four (four being most vulnerable) and summing the values for all vulnerabilities and hazards to create a composite score. No weighting was applied to any of the variables. As a result of this methodology, the assessment demonstrated that areas with high population vulnerability could surpass counties with higher occurrences of climate hazards in overall composite vulnerability. This may suggest that in the event of a climate hazard, counties with higher population vulnerability may need more planning and assistance.

Limitations of the climate change vulnerability assessment include reliance on historic weather and vector-borne disease surveillance, as well as, recent demographic data; limited data availability; varying levels of data accuracy; potential masking of disparities through data aggregation and geographic display; and lack of validation of the methodology used in the composite vulnerability scores. However, this assessment provides an initial attempt at quantifying and visually displaying climate change vulnerability in Minnesota. MDH intends to further this work by conducting additional assessments with local public health departments at finer geographic scales and using this information to start a dialogue about climate change vulnerability that will lead to climate change adaptation planning at local levels.

II Introduction

The MDH conducted the following Climate Change Vulnerability Assessment (CCVA) for the state of Minnesota between the months of November 2012 and August 2014. The purpose of the CCVA is to assess population vulnerabilities by county for the following climate hazards: extreme heat events, air pollution, vector-borne diseases, flooding and flash flooding, and drought. The CCVA is a pilot project intended to further the work of assessing population vulnerability to climate change; explore the application of CCVA concepts and methods in the context of Minnesota; identify necessary datasets and their strengths and weaknesses for use in CCVA; and to start a dialogue about climate change vulnerability. The CCVA is not meant to infer causal relationships. The focus of this project is to assess vulnerability to climate change using historical data. The project does not address adaptation nor resiliency, nor does it predict future vulnerability.

The terms hazard, risk and vulnerability are used throughout the report. A hazard or climate hazard can be defined as a natural disaster or weather event (e.g., flood, drought or extreme heat), an environmental condition (e.g., poor air quality), or biological threat (e.g., tick-borne disease), which has the potential for causing harm to persons, property, or ecosystems. Generally speaking, a hazard becomes a problem to society when it negatively affects people, property and livelihoods. For example, there is a significantly greater societal impact when a flood occurs in highly populated area versus an undeveloped river valley. The flood's impact on ecosystems is important, but it is beyond the scope of this effort. This report will only address hazards that have direct impacts on humans.

Risk refers to the probability that an event will occur (Burt, 2001). In the discussions that follow risk can be thought of in two ways. First, risk is the probability that a natural disaster or weather event related to climate

A family vacationing in the Boundary Waters Canoe Area Wilderness is at risk of harm or injury if a wildfire (hazard) starts in their vicinity.

change will occur at a particular location. Second, risk can be thought of in terms of personal risk or population risk. This understanding of risk is based on the probability that a person or group of persons (e.g., workers employed in agricultural industry) is located in the path of a hazard (e.g., a flood-prone area).

Persons or populations more vulnerable to the five climate hazards outlined in this report are referred to as "vulnerable populations." Vulnerable populations are groups of people that share a similar characteristic or characteristics that make them more vulnerable to a hazard. Characteristics that can increase population vulnerability include age, gender, education level, income, and health status (Wisner et al, 2003).

It is important to make two clarifications about the concept of vulnerability. First, vulnerability is situational. This means that a person or population that has one of these characteristics of vulnerability (e.g., being disabled) may only be at risk in the context of an event or hazard; it does not necessarily imply inherent vulnerability (Wisner et al, 2003). Second, vulnerability may be a temporary status, such as age, pregnancy, or homelessness. The intent of this report is not to single out any population as a class of victims, but rather to identify populations for whom extra care and consideration should be taken when assessing the potential impact of hazards on a community. More detail is provided in the following chapters on how these characteristics contribute to group vulnerability to specific hazards.

Hazard, risk and vulnerability combine to affect a health outcome (hazard + risk + vulnerability = outcome). The outcome is predicated on whether the event is a hazard, the probability that the event will happen, and whether vulnerable populations are present that will struggle to prepare for and recover from the event. Each climate hazard chapter is outlined in a way that describes the hazard, the risk for each hazard by county based on historical data, and where the vulnerable populations are located.

A 75-year old woman living alone in the top unit of a senior living apartment building in downtown minneapolis is both at risk of heat-related illness if there is an extreme heat event and more vulnerable to extreme heat because of multiple physiological and socio-demographic factors, which makes her more likely to experience a heat-related illness.

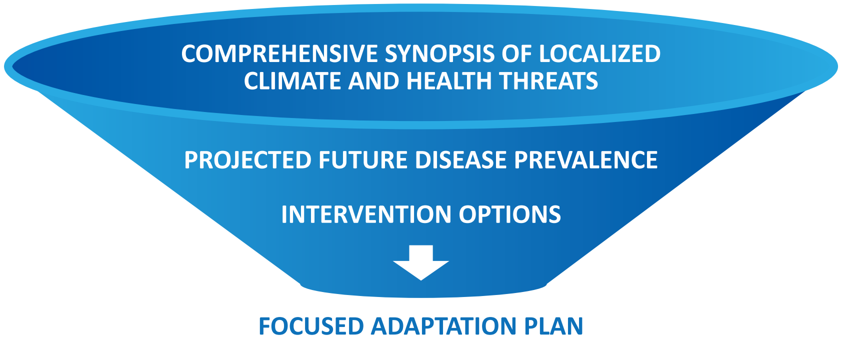
III Background: Climate Change and Vulnerability

In 2012, the Centers for Disease Control and Prevention (CDC) released a framework titled Building Resilience Against Climate Effects (BRACE), which guides CDC's Climate and Health grantees through a step-by-step process to address climate change. The five steps of the framework are 1) anticipating climate impacts and assessing vulnerabilities; 2) projecting disease burden; 3) assessing public health interventions; 4) developing and implementing a climate and health adaptation plan; and 5) evaluating impact and improving quality of activities. The framework provides a data-driven approach to understanding, prioritizing and implementing strategies to prevent the negative health impacts of climate change. See Figure III-1 for a visual depiction of the BRACE framework prioritization process.

This report provides an initial assessment of vulnerabilities as required by BRACE Step 1. The next two sections of this report include a background on climate change in Minnesota and a summary of the literature review that MDH conducted to identify the populations that are more vulnerable to the effects of the observed and projected climate changes. For more information on observed climate changes and future projections in Minnesota and the corresponding health effects, refer to the Minnesota Climate & Health Program website at http://www.health.state.mn.us/divs/climatechange.

By completing this CCVA, MDH is establishing a foundation for future climate change work that will include projecting disease burden, assessing public health interventions, developing and implementing climate change adaptation plans and evaluating and improving efforts.

FIGURE III-1: BRACE FRAMEWORK



Source: CDC, 2013

Climate Change in Minnesota

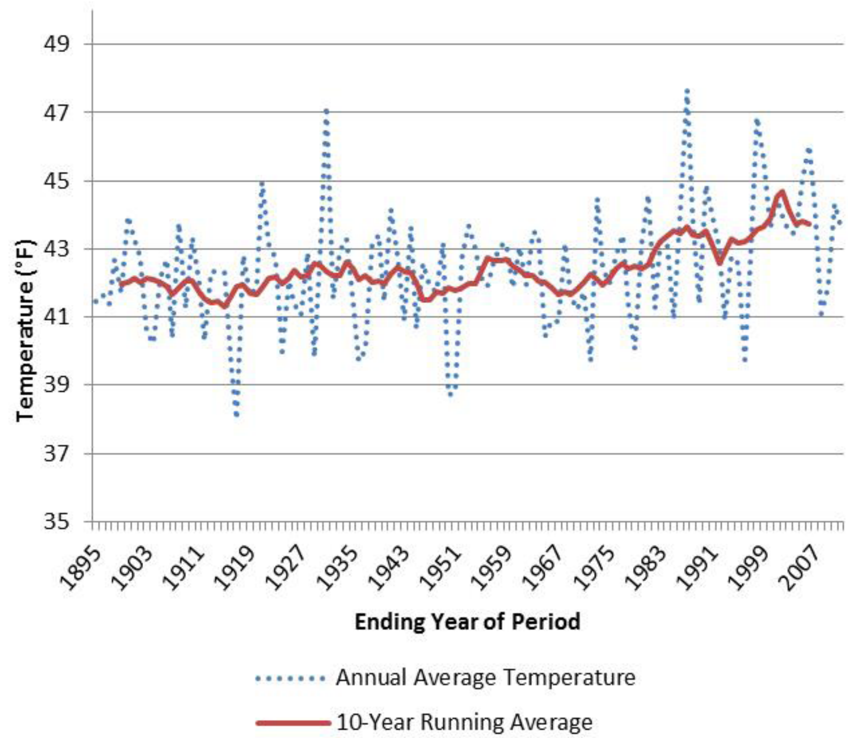
Climate change refers to any significant change in measures of the atmosphere lasting for an extended period of time. Climate change often refers to major changes in temperature, precipitation, or wind patterns, among other effects, that occur over several decades or longer. By contrast, weather refers to conditions of the atmosphere that may fluctuate over a short period of time. For example, describing today's temperature and chance of rain are references to the weather. While specific storm events are weather, the frequency, intensity and distribution of storms are influenced by climate. Changes in climate are increasing storm frequency and intensity and changing distribution patterns.

In Minnesota, there are three climate change trends that are a focus of concern. First, average temperature is increasing across all seasons. Minnesota temperature records go back to 1891 with the start of the National Weather Service records.

With regard to average annual temperature, little change was apparent in the first 90 to 100 years of the records, but a clear upward trend has been observed starting in the 1980s (Figure III-2) (WRCC, 2011). According to a national study on temperature trends, Minnesota was the ninth fastest warming state in the country since 1912 and the third fastest warming state since 1970 (Tebaldi et al, 2012). Average temperatures increased over 0.2 degrees Fahrenheit (°F) per decade between 1912 and 2012, and over 0.5°F per decade between 1960 and 2013 (NCDC, 2014).

Within the overall warming pattern, there are two significant underlying trends. First, winter temperatures are rising twice as fast as annual average temperatures. Second, minimum or over-night low temperatures are rising faster than maximum or daytime high temperatures (Zandlo, 2008). These underlying trends are important for understanding how overall changes in average temperatures impact ecosystems and human populations. For example, the long term viability of plant and wildlife species that rely on a limited range of winter temperatures to cue or enable certain life cycle stages may be adversely impacted. Warmer winters also may support the overwintering of pests, leading to increases in vector-borne diseases during the spring and summer months. Freeze-thaw cycles may increase, which can damage infrastructure. More precipitation may fall as rain than

FIGURE III-2: MINNESOTA AVERAGE TEMPERATURE 1890 – 2010: 12-MONTH PERIOD ENDING IN DECEMBER



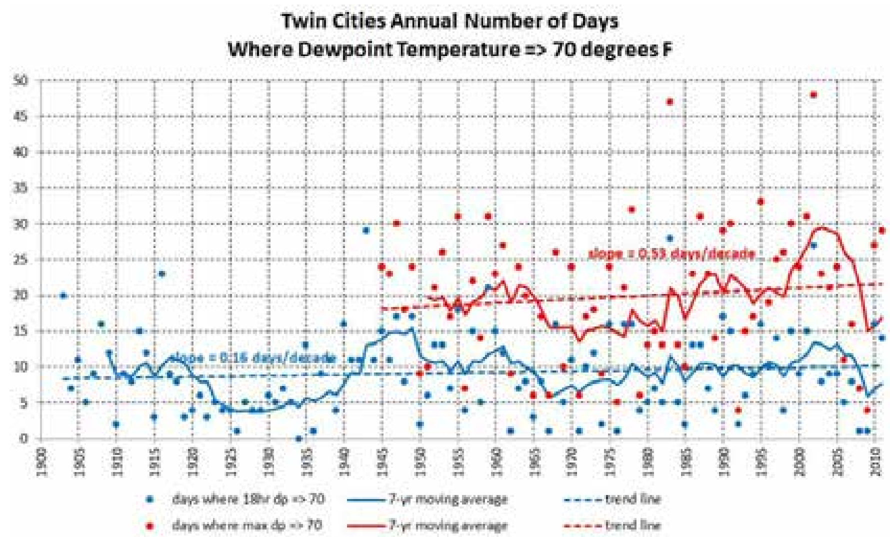
Data source: Western Regional Climate Center, 2011 snow which can lead to less snow cover protecting dormant crops from cold temperatures. Additionally, overnight low temperatures, particularly in the summer months, are important for allowing buildings and people to cool off during hot days. If overnight low temperature are rising faster than daytime high temperatures, we could see less overnight cooling, more heat stress and, as a result, an increase in heat-related illnesses and deaths.

The second major climate change trend confronting Minnesota involves a potential increase in the number of days with a high dew point temperature (equal to or greater than 70°F) (Seeley, 2012). The dew point temperature is a measure of water vapor in the air (i.e., humidity) (Horstmeyer, 2008). High dew point temperatures on warm days can limit the ability of a person's sweat to evaporate, which is the primary way the body cools itself. This can lead to a range of issues from mild discomfort to serious illness. A dew point temperature of 70°F feels uncomfortable and is often used as a threshold measuring high dew point temperatures. Dew point temperatures above 70°F feel increasingly oppressive. Records collected in the Twin Cities show that the number of days associated with a maximum dew point temperature greater than or equal to 70°F increased from 1945 to 2010 (Figure III-3), although the increase was not statistically significant.

The third major climate change trend confronting Minnesota involves changes in the character of precipitation. On average, precipitation in Minnesota has increased since the beginning of the National Weather Service (NWS) records. Most of the increase can be observed since the Dust Bowl era of the 1930s (Figure III-4). While climate scientists are not sure if this trend will continue, most agree that the character of precipitation is changing. Specifically, Minnesota is experiencing an increase in localized, heavy precipitation events (Pryor et al, 2014). In the areas where these rain events occur, localized flooding may occur. Other areas of the state may receive no rain and experience a deficit that could lead to drought conditions.

Based on what is known about Minnesota's changing climate, MDH focused on five hazards for the vulnerability assessment: extreme heat events, air pollution, vector-borne diseases, flooding and flash flooding, and drought.

FIGURE III-3: TWIN CITIES ANNUAL NUMBER OF DAYS WHERE DEW POINT TEMPERATURE => 70 DEGREES F



Source: Seeley M. 2012. Climate Trends and Climate Change in Minnesota: A Review . Minnesota State Climatology Office. http://climate.umn.edu/seeley/

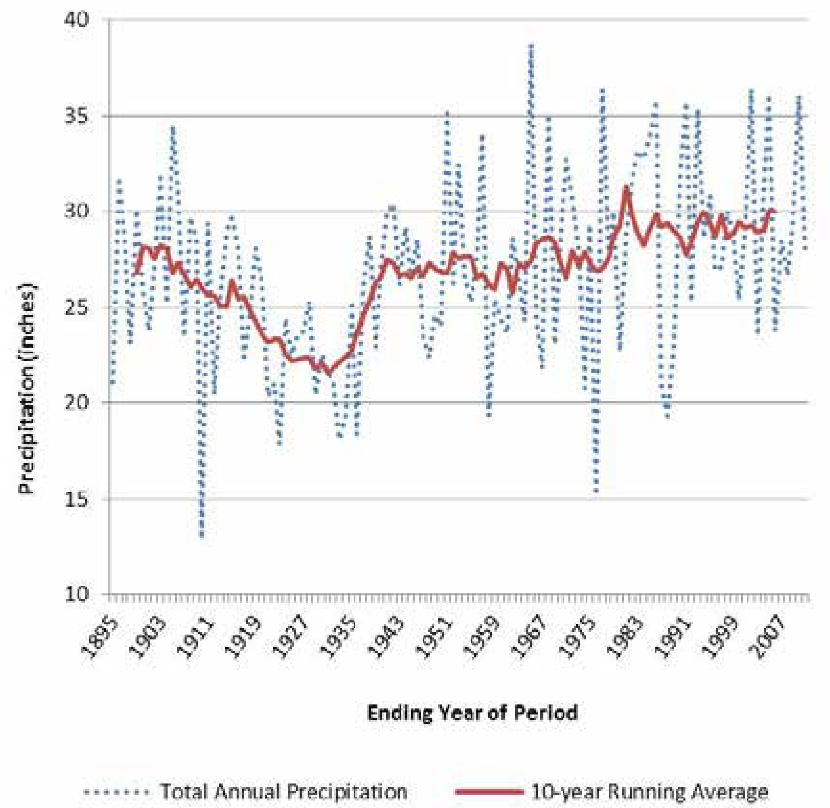
Review of Vulnerability Assessments

Although climate change vulnerability assessments are growing in popularity, there are relatively few completed examples. Examples include the Association of State and Territorial Health Officials (ASTHO) Climate Change Population Vulnerability Screening Tool (2012), the Vulnerability and Risk Assessment chapter of Flagstaff's Resiliency and Preparedness Study (2012), and the San Luis Obispo County Preliminary Climate Change Vulnerability Assessment for Social Systems (2010). Additionally, there is no standard methodology to follow. However, community hazard-mitigation plans may have some similarities to climate change vulnerability assessments.

MDH initiated the CCVA for Minnesota with a review of existing reports on climate change indicators and literature on vulnerable populations. MDH consulted fourteen of the most cited existing studies on populations vulnerable to natural hazards and climate change, and methodologies for conducting vulnerability assessments and two example climate change vulnerability assessments. The review of the studies is provided in Appendix A.

Based on this literature review, MDH developed a master list of indicators of vulnerability to natural hazards and climate change. The list included every indicator mentioned in a source whether or not it applied to Minnesota or had available data. The master list of indicators is provided in Appendix B. The list was sorted according to the following categories: climate hazard, health risk, population vulnerability, and built environment hazard. Subcategories for climate hazards included heat, air quality, drought, flood, extreme heat, flood, infectious disease, water quality and wildfire. Data sources for the indicators were identified wherever possible and are listed in Appendix B.

FIGURE III 4: MINNESOTA TOTAL ANNUAL PRECIPITATION 1890 – 2010: 12-MONTH PERIOD ENDING IN DECEMBER



Data source: Western Regional Climate Center, 2011

Methodology varies among existing vulnerability assessments. MDH chose to use the ASTHO Climate Change Population Vulnerability Screening Tool, developed and piloted by the California Environmental Public Health Tracking (EPHT) program at the California Department of Public Health. California EPHT developed an index of population vulnerability based on an environmental justice screening method, developed by Sadd et al. (2011), and combined it with indicators of climate change vulnerability. The environmental justice screening method included combined measures of hazard proximity and land use sensitivity, health risk and exposure, and social and health vulnerability (Table III-1). Climate change vulnerability indicators included air conditioning ownership, impervious surfaces, tree canopy, public transit routes, household car access, elderly living alone, flood risk, and wildland-urban interface.

The ASTHO Climate Change Population Vulnerability Screening Tool used an additive model to create a vulnerability index. The values for each of the indicators were broken into four equal groups (quartiles), each group comprising a quarter of the data. The first quartile, representing lowest vulnerability, was given a value of 1; the second quartile a value of 2; the third quartile a value of 3; and the fourth quartile a value of 4, representing the highest level of vulnerability. Once each of the indicators had been distributed and assigned values, a combined climate change population vulnerability score was created by averaging the value of all environmental justice and climate change vulnerability indicators.

MDH used this methodology for creating the county-level composite maps for three climate hazards: extreme heat events, air pollution and flooding. The composite maps are described within their respective chapters.

The next five chapters provide an overview of each hazard selected for Minnesota's CCVA, data available for each hazard in Minnesota, relevant vulnerable populations, expectations for how climate change is expected to affect the hazard, and potential health outcomes.

TABLE III-1: ENVIRONMENTAL JUSTICE AND CLIMATE CHANGE INDICATORS

Hazard Proximity and Land Use Sensitivity	Health Risk and Exposure	Social and Health Vulnerability	Climate Change Vulnerability
Hazards: hazardous waste sites, railroad facilities, refineries Sensitive land uses: childcare and health care facilities, schools, playgrounds, senior housing	Particulate matter and ozone concentrations, estimated cancer risk from modeled ambient air toxics concentrations	Race, poverty, educational attainment, age, birth outcomes	Air conditioning ownership, impervious surfaces, tree canopy, public transit routes, household car access, elderly living alone, flood risk, and wildfire urban interface

Source: California EPHT, ASTHO Climate Change Population Vulnerability Screening Tool, California Department of Public Health. 2012.

IV Extreme Heat Events

Background

Extreme heat is not new to Minnesota. However, Minnesotans are less accustomed, or acclimated, to extreme heat than extreme cold. The Minneapolis Weather Bureau's summary of July 1936 describes the impact of an extreme heat event in Minnesota:

"The period from the 5th to the 18th was the hottest period of such duration ever experienced in Minnesota. The extreme heat resulted in innumerable heat prostrations, many fatal. A large news gathering agency estimated the number of deaths in the state at 759, attributed directly or indirectly to the heat wave. There was much suffering to livestock, with attendant losses. In streams tributary to Lake Superior and in the southeastern part of the state, severe losses to game fish occurred, particularly in the trout streams, when surface water temperature rose to as high as 85 degrees. There were more forest fires started during the period of extreme heat than in any like period since the organization of the state forestry and fire prevention service in 1911. Lake and stream levels were affected considerably by the excessive evaporation. There was some damage to highways." (St. Martin, 1936)

Extreme heat can be measured by the heat index that takes into account both air temperature and dew point temperature. The heat index measures the apparent temperature, or how hot the weather feels to the body. For example, 90°F air temperature is experienced by the human body as 108°F if the dew point temperature is 80°F.

Extreme heat definitions vary across the U.S. Because Minnesota is a northern state with cooler temperatures than southern states, an extreme heat event is defined differently in Minnesota than it would be in Texas, for example. The NWS declares a heat advisory or warning depending on the location of the station issuing the alert and the weather in its own service area. There are six NWS stations serving Minnesota (Figure IV-1).

It should be noted that in some cases, the NWS station serving Minnesota communities may be located in another state.

FIGURE IV-1: NWS STATIONS SERVING MINNESOTA

Source: National Weather Service

Table IV-1 provides the definitions of heat advisory and excessive heat warning issued by the Twin Cities/Chanhassen NWS Office for Hennepin and Ramsey counties and most of central Minnesota. Other NWS stations serving Minnesota counties have similar thresholds for heat advisory and heat warning.

TABLE IV 1: DEFINITIONS OF HEAT ADVISORY AND EXCESSIVE HEAT WARNING

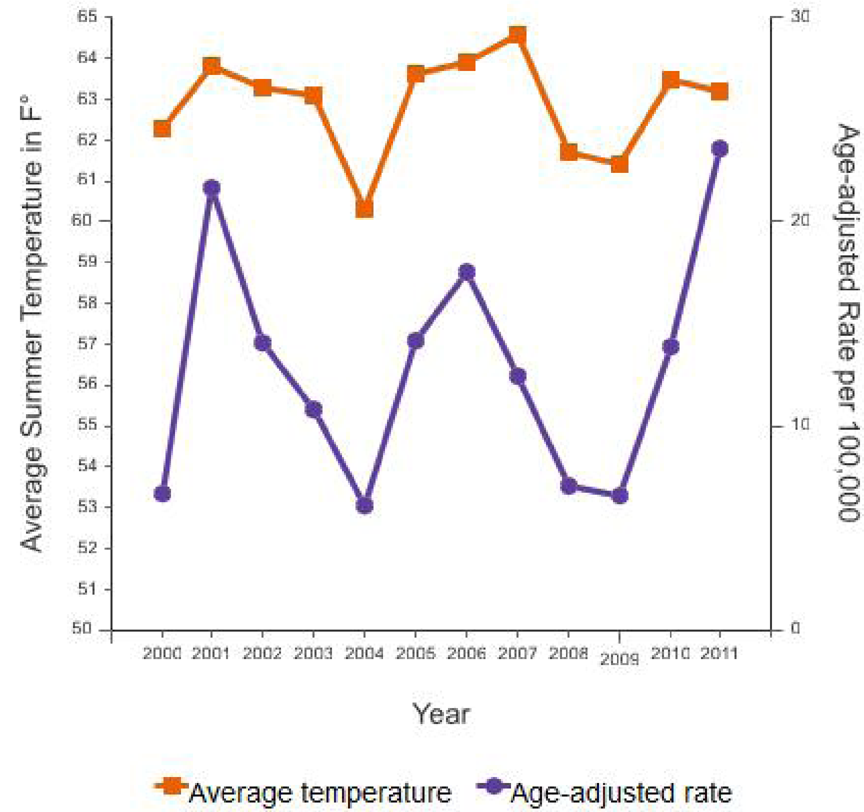
HEAT ADVISORY	**Hennepin & Ramsey Counties**	**All Other Counties**
Heat Advisories are issued when an extreme heat event is expected in the next 48 hours. These statements are issued when an extreme heat event is occurring, is imminent, or has a very high probability of occurring. An advisory is for less serious conditions that cause significant discomfort or inconvenience and, if caution is not taken, could lead to a threat to life and/or property.	Maximum heat index at Minneapolis/St. Paul International Airport is expected to reach 95°F or greater for 1 day, or the maximum heat index is expected to reach 95°F or greater and an overnight low temperature no cooler than 75°F for 2 days in a row.	Maximum heat index reaches 100°F and/or the maximum temperature reaches 95°F or higher.
EXCESSIVE HEAT WARNING	**Hennepin & Ramsey Counties**	**All Other Counties**
Excessive Heat Warnings are issued when an extreme heat event is expected in the next 48 hours. These statements are issued when an extreme heat event is occurring, is imminent, or has a very high probability of occurring. A warning is used for conditions posing a threat to life or property.	Maximum heat index at Minneapolis/St. Paul International Airport reaches 100°F or greater for at least 1 day. In addition, the Heat Watch/Warning System, a tool develop based on research, must recommend a warning. A warning may also be issued if advisory criteria are expected for 4 days in a row.	Maximum heat index reaches 105°F or greater and a minimum heat index of 75°F or greater for at least 48 hours. A warning may also be issued if advisory criteria are expected for 4 days in a row.

Source: National Weather Service. 2012. Watch, Warning, and Advisory Definitions for NWS Twin Cities.

Extreme Heat in Minnesota

Extreme heat impacts health directly by causing heat-related illness and indirectly by exacerbating existing illnesses and health conditions. When a person is exposed to high heat and humidity, body temperature may increase above normal (98.6°F). Illness may result if the body cannot cool down, and core temperature increases. Symptoms of heat-related illnesses can include heat rash, swelling in the extremities (edema), breathing difficulties, muscle cramps, dizziness or fainting, profuse sweating, weakness, nausea or vomiting, dehydration, headache, confusion, loss of consciousness, and even death (CDC, 2006a; Platt & Vicario, 2010; Zimmerman & Hanania, 2005). Figure IV-2 shows the Minnesota age-adjusted rate of emergency department visits for heat-related illnesses in relation to average summer temperature. While average summer temperature does not tell us whether there was an extreme heat event, the data do show that the rate of emergency department visits is generally higher for heat-related illnesses during summers with higher average temperatures.

FIGURE IV-2: HEAT-RELATED ILLNESS EMERGENCY DEPARTMENT VISITS*



*Emergency department (ED) visits are directly heat-related and per 100,000 people.

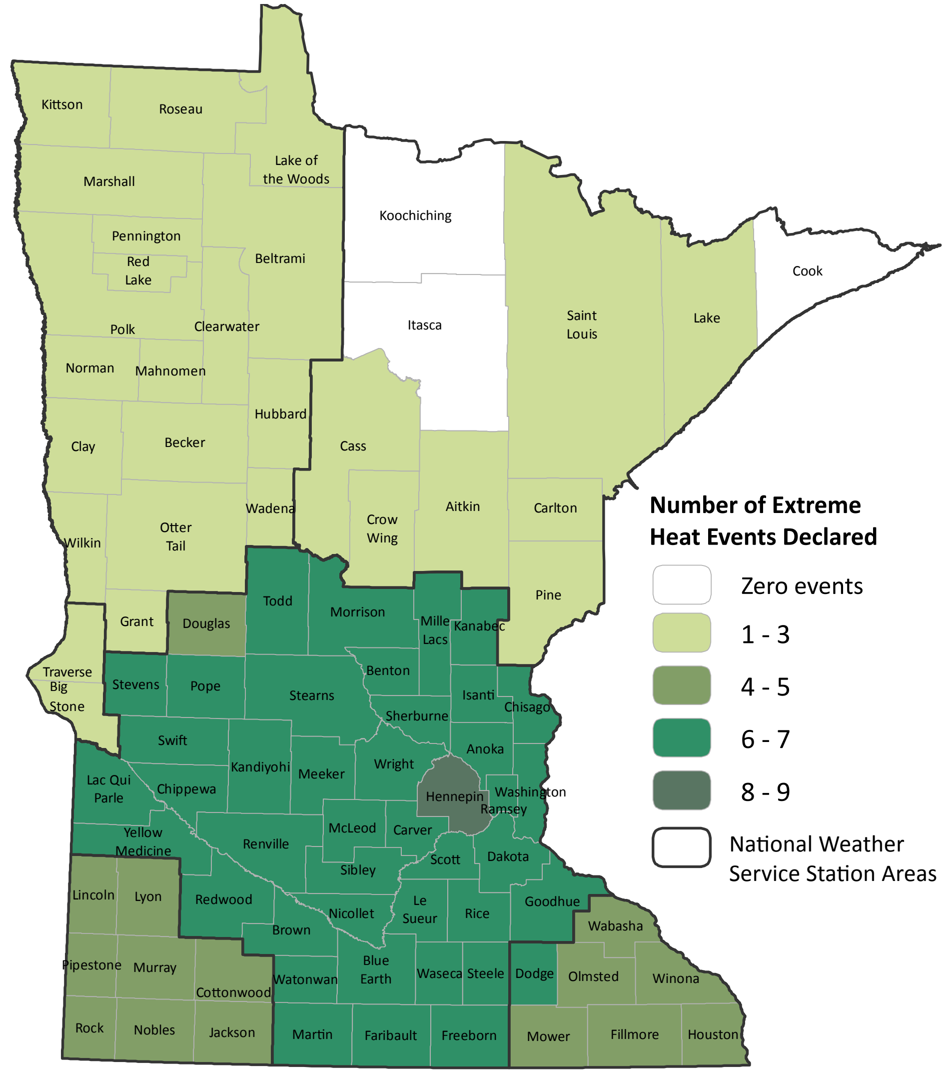
Source: Minnesota Environmental Public Health Tracking, Heat-related illness, 2013

Not all areas of Minnesota have had the same number of heat event declarations. Figure IV-3 shows the number of declared heat events from 1995 to 2012, including both excessive heat warnings and heat advisories combined, from the National Climatic Data Center's (NCDC) Storm Data (NCDC, 2013a). This data set does not include all the events; rather, it only includes events that were "significant" (when NOAA received notable reports about injuries/deaths/property loss through emergency management officials, etc). A lot of the advisory events may not be written up into the storm events database because NOAA does not receive impact reports unless they are relatively major in number or extent of impacts (Lisa Schmidt, NOAA, personal communication, September 29, 2014).

Figure IV-3 indicates that counties in central and southern Minnesota have had significant heat or excessive heat events more often than counties in northern Minnesota. This is likely due to a combination of factors, including regional climate, vegetation and land use, the weather forecast in the area of the issuing NWS station, and the slight differences in distinctions of heat events between NWS stations.

All of the counties in the darkest green in central and south-central Minnesota are covered by the Twin-Cities/Chanhassen NWS station. The counties in lighter green in southwestern and southeastern Minnesota are covered by the Sioux Falls and La Crosse NWS stations, respectively. Northwestern and northeastern Minnesota, where few significant heat events occurred in the past 18 years, are covered by the Fargo/Grand Forks and Duluth NWS stations, respectively.

FIGURE IV-3: NUMBER OF EXTREME HEAT EVENTS BY COUNTY 1995-2012



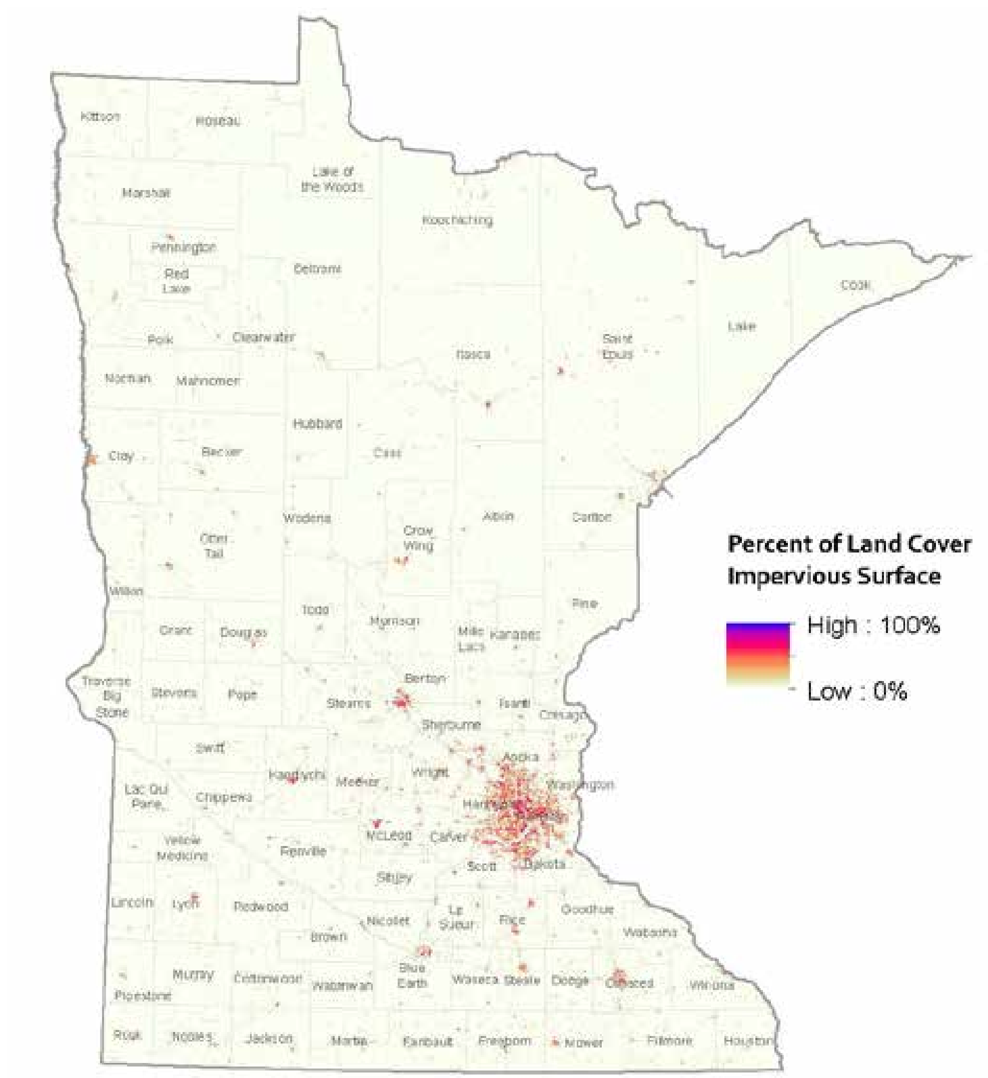
Data source: NOAA National Climatic Data Center (NCDC, 2013).

Urban areas and even small cities often experience the urban heat island effect. This effect is the result of reduced vegetation and increased impervious surfaces, such as pavement and rooftops, absorbing the heat from the sun throughout the day and releasing the heat at night when temperatures drop, effectively making these areas warmer than rural or undeveloped areas (U.S. EPA, 2008). Also, the urban heat island effect is impacted by properties of urban materials, anthropogenic heat, and other factors.

The urban heat island effect can result in a temperature difference between urban and rural areas in excess of 5°F during the daytime and as much as 22°F on calm, cloudless summer nights (Akbari, 2005). While the urban heat island effect might sound like a nice benefit during cold Minnesota winters, during the summer months the temperature difference can be critically important for the health of urban residents if they do not get the relief from the daytime heat during the night.

Figure IV-4 shows percent of land cover that is impervious, such as rooftops, roads and parking lots, across Minnesota. Data for impervious land cover are characterized by the National Land Classification Database from 2006 satellite imagery produced by the Multi-Resolution Land Characteristics Consortium (Yang et al., 2003). Impervious surface, while not a perfect measure, provides an indication of where the urban heat island effect might be observed. The high percentages of impervious surface in the Twin Cities metro area stands out most notably, as well as St. Cloud, Rochester, Duluth and other cities in the state. It is important to note that smaller cities are not immune; every area emphasized by red or purple (to demonstrate higher percentages of impervious surface) experiences some degree of the urban heat island effect.

FIGURE IV-4: IMPERVIOUS LAND COVER



Data source: National Land Classification Database, 2006

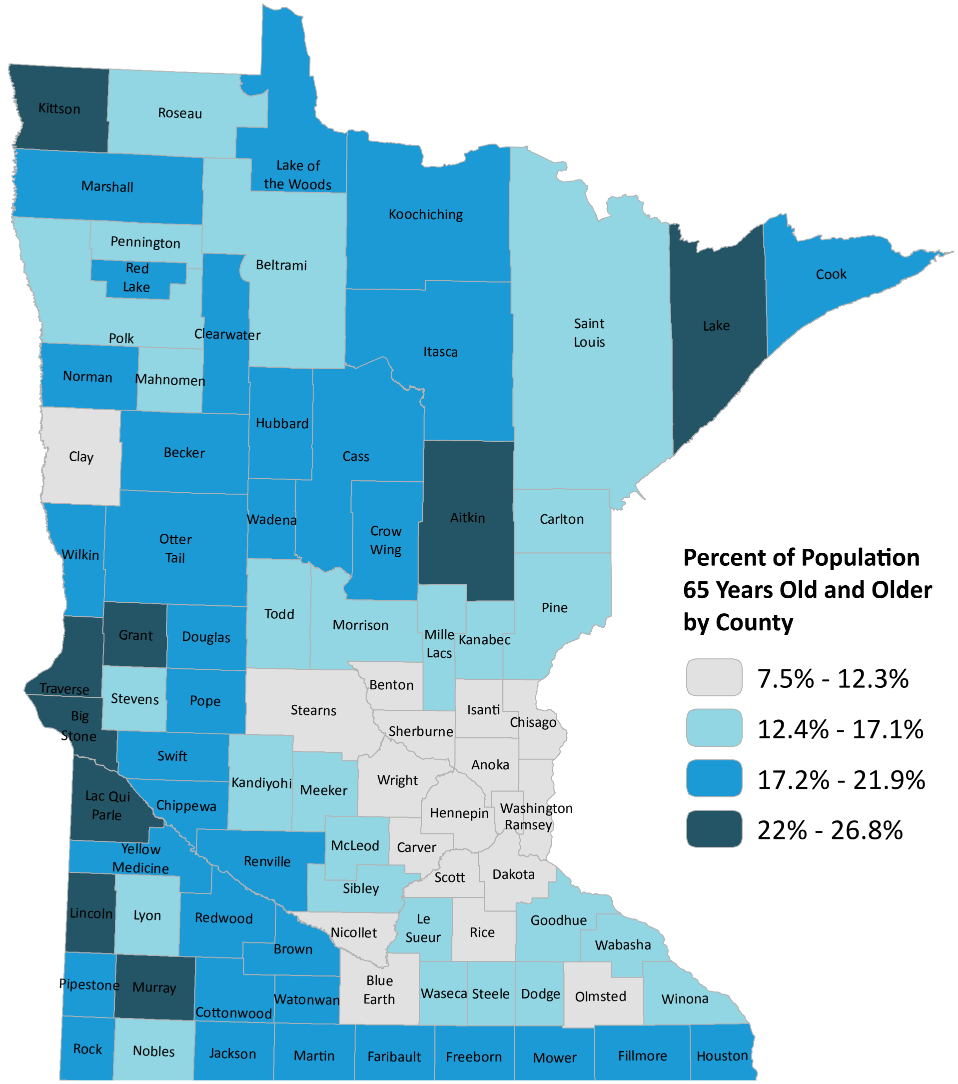
Populations Vulnerable to Extreme Heat

Everyone is at risk for heat-related illnesses, but certain populations are more vulnerable to extreme heat, such as older adults, young children and babies, homeless persons, persons living in poverty or those without access to air-conditioning, persons of color, persons with pre-existing health conditions, persons using certain medications, persons living in nursing homes or who are bedridden, and persons living alone. Populations at higher risk to extreme heat include outdoor workers, athletes exercising outside, persons living in urban areas, and persons living in top-floor apartments (given that warm air rises).

Older adults (65 years and over) are the population with the highest rates of heat-related illness and deaths (Bouchama & Knochel, 2002; Knowlton et al., 2009). Certain physiological changes associated with aging, such as the body's decreased ability to control body temperature, increase older adults' risk of experiencing heat-related illnesses (Foster et al., 1976). Chronic disease conditions and the use of certain medications also may increase older adults' susceptibility to adverse health outcomes from heat (Schifano et al., 2009).

Figure IV-5 shows the percentage of persons who are 65 years old and older by county. Percentages of older adults are highest in western Minnesota counties of Traverse, Big Stone, Laq Qui Parle, Grant, Lincoln and Murray where extreme heat events are more prevalent. High percentages of older adults in Kittson County in the northwest, and Aitkin and Lake counties in the northeast may be less at risk for heat-related illness due to lower counts of extreme heat events. The largest population of older adults (128,374) is located in Hennepin, where heat events have been declared most often (nine events between 1995 and 2012).

FIGURE IV-5: OLDER ADULTS - PERCENT OF POPULATION 65 YEARS OLD AND OLDER BY COUNTY



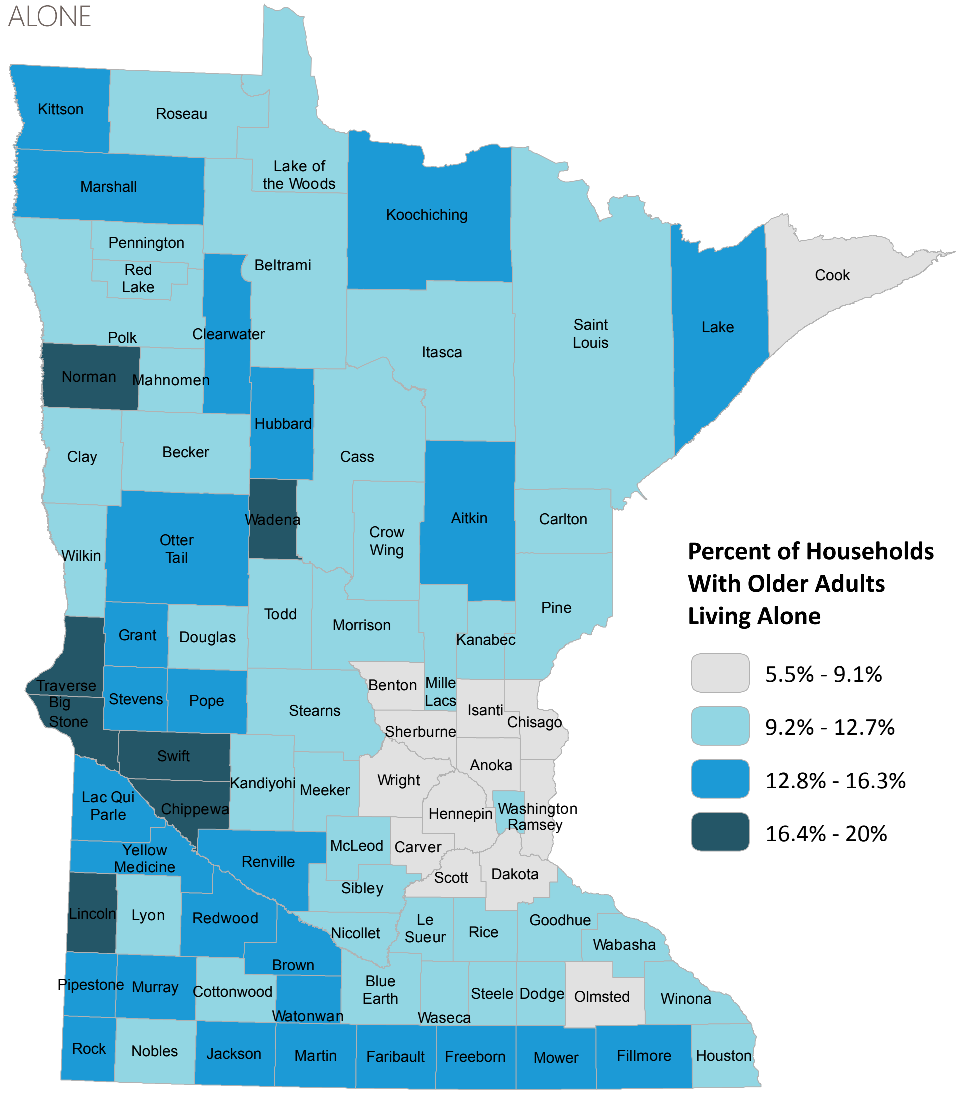
Data source: American Community Survey 5-year Estimates, 2007-2011.

Older adults who live alone and/or at or below the poverty line are particularly vulnerable to negative health outcomes from extreme heat because of a combination of factors associated with aging, social isolation, and economic constraints (CCSP, 2008).

Figure IV-6 shows the percentage of households that have single-occupants 65 years or older. Similar to Figure IV-5, the higher percentages of households with older adults living alone are in western Minnesota. There are also a number of counties with a higher percentage of older adults living alone in southern Minnesota that could be at risk for more extreme heat events. The largest population of households with older adults living alone is in Hennepin County (42,785), followed by Ramsey (19,855) and Dakota (11,060) counties.

Children, especially children under five years, have a greater risk for heat-related illness and mortality during hot weather due to a range of factors, including the following: dependency on other people for care; physiological differences, including smaller body mass to surface area ratio compared to adults; blunted thirst response; production of more metabolic heat per pound of body weight; and lower cardiac output (Rowland, 2008; Bytomski & Squire, 2003).

FIGURE IV-6: OLDER ADULTS LIVING ALONE- PERCENT OF HOUSEHOLDS WITH PERSONS 65 YEARS OLD AND OLDER LIVING ALONE

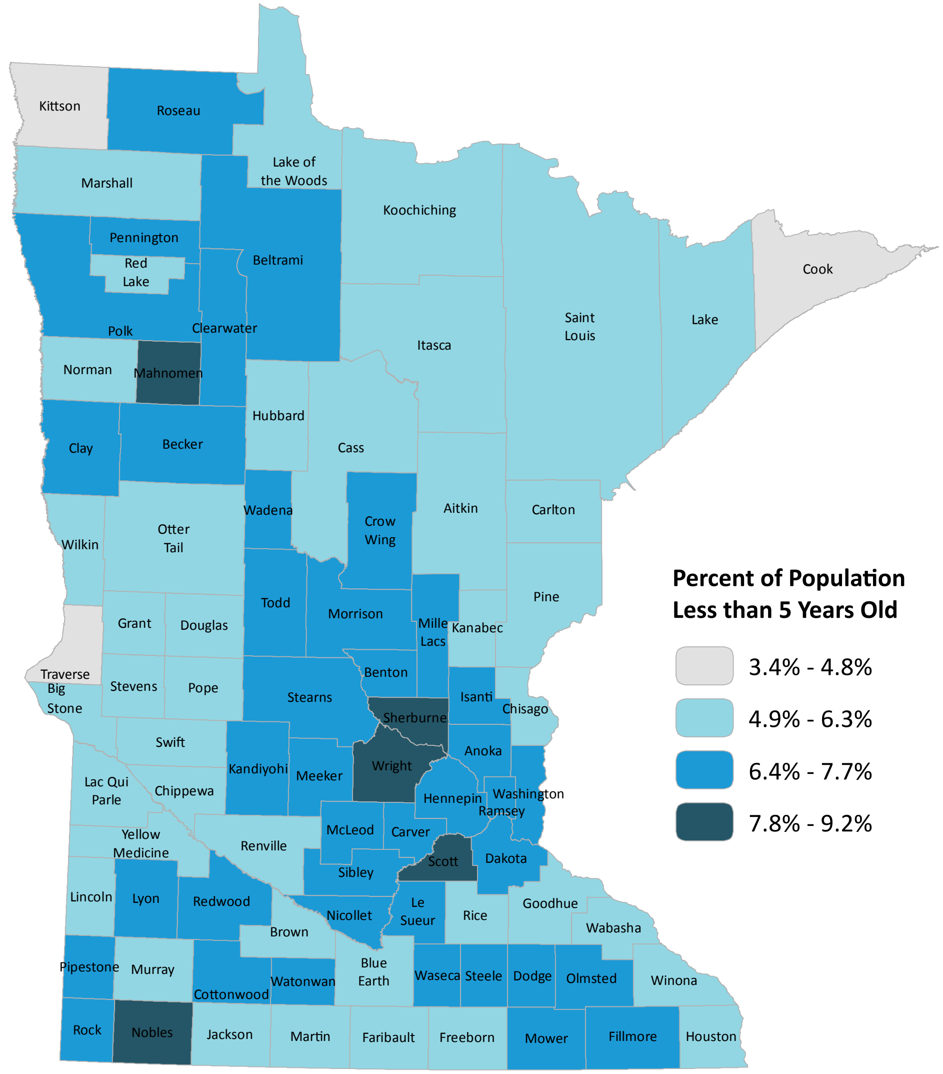


Data source: American Community Survey 5-year Estimates, 2007-2011.

Figure IV-7 shows the percentage of population less than five years old by county. The map shows that there are higher total counts and percentages of young children in the Twin Cities and surrounding counties. There are also higher percentages of young children in northwestern Minnesota, in Mahnomen and surrounding counties, as well as southwestern and southeastern Minnesota. Based on historical weather data, young children in the metro-area and southern Minnesota may be likely to be exposed to extreme heat and therefore be at a higher risk for heat-related illnesses.

Low socioeconomic status increases risk of heat-related mortality (O'Neill et al., 2003). Persons living at or below the poverty line are less likely to have air conditioners in their homes (Hajat et al., 2007; Curriero et al., 2002), more likely to live in deteriorating and substandard homes (Semenza et al., 1996), and may have difficulty paying for increased electricity usage during an extreme heat event. Persons living at or below the poverty line might be more concerned about safety, and therefore be unwilling or unable to seek cooling centers or open doors and windows to increase circulation (AMACSA, 1997).

FIGURE IV-7: YOUNG CHILDREN - PERCENT OF POPULATION LESS THAN 5 YEARS OLD BY COUNTY

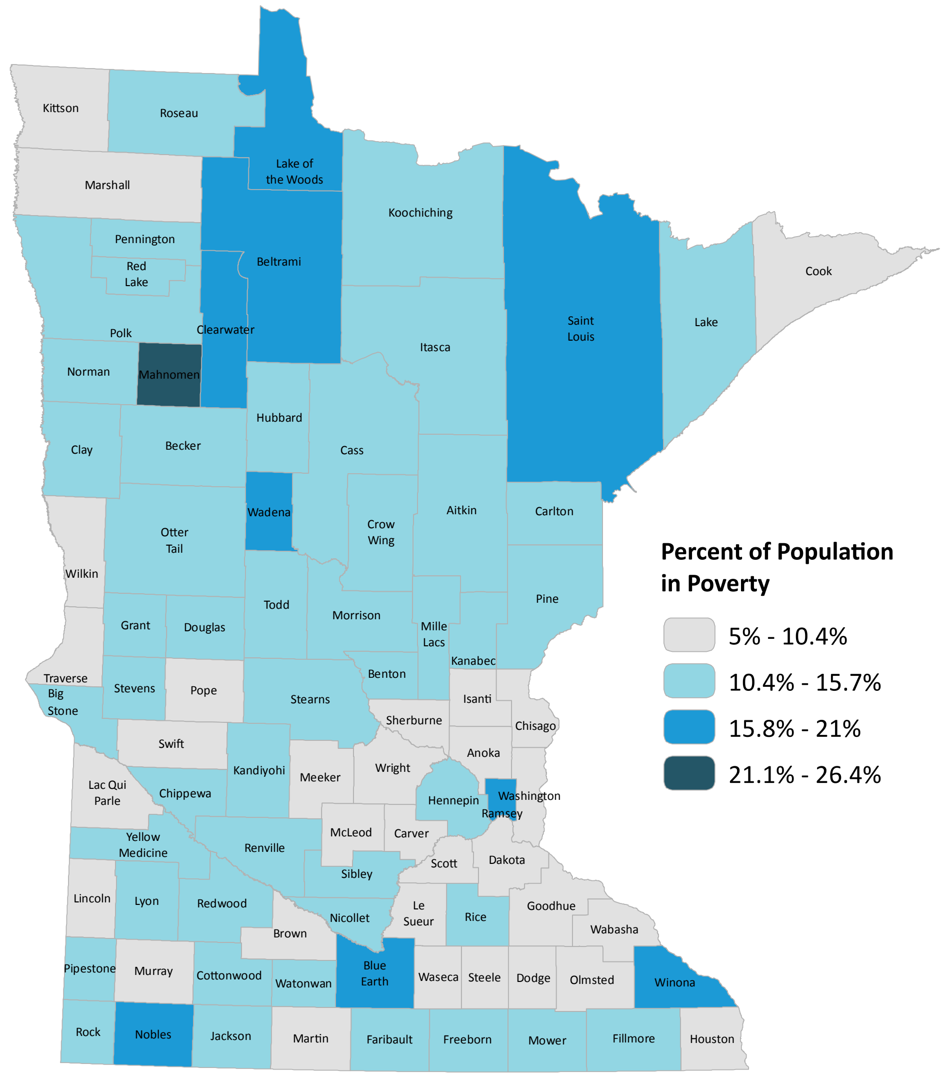


Data source: American Community Survey 5-year Estimates, 2007-2011.

Figure IV-8 shows the percentage of the population that lives in households with an annual income at or below the poverty threshold. As of the 2011 American Community Survey, the poverty threshold for a single person household was $11,484 (US Census Bureau, 2011). Poverty is highest in the northern Minnesota counties of Mahnomen, Clearwater, Beltrami and Lake of the Woods, as well as the counties of Wadena, St. Louis, Ramsey, Nobles, Blue Earth and Winona. The largest populations of persons in poverty are in Hennepin (138,258) and Ramsey (80,612) counties. Persons in poverty in central and southern Minnesota may be more at risk for heat-related illnesses due to the greater incidence of heat event declarations.

In addition to low socioeconomic status, race may increase vulnerability to heat-related illness and mortality. Studies have shown higher rates of renal failure, hospital admissions for cardiovascular and respiratory disorders, and heat-related mortality in persons of color, particularly in the African American population (O'Neill et al., 2003; Fletcher et al., 2012; Lin et al., 2009; Whitman et al., 1997; McGeehin & Mirabelli, 2001; Kalkstein, 1992). The health disparities among populations of color may be a result of a number of sources, including "cultural differences in lifestyle patterns, inherited health risks, and social inequalities that are reflected in discrepancies in access to health care, variations in health providers' behaviors, differences in socioeconomic position, and the effects of race-based discrimination" (Mays et al., 2007).

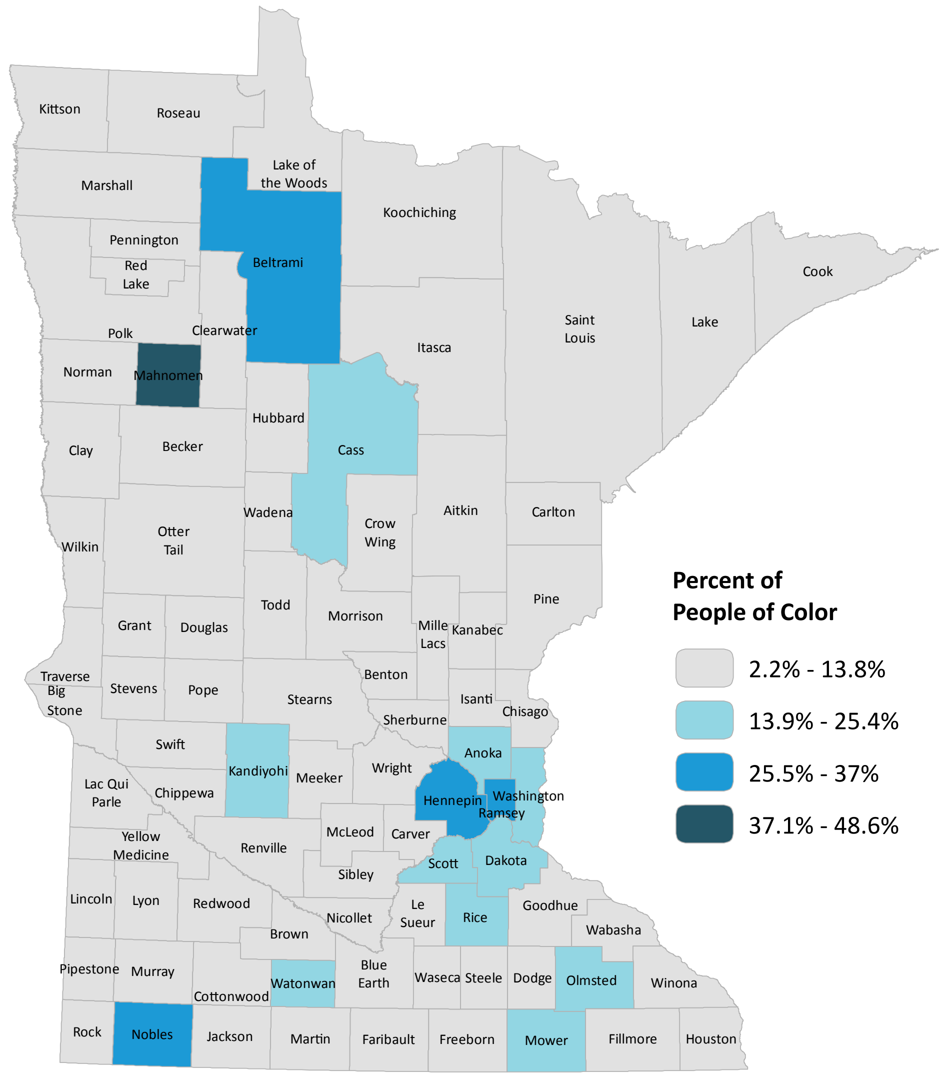
FIGURE IV-8: PERCENT OF POPULATION IN POVERTY BY COUNTY



Data source: American Community Survey 5-year Estimates, 2007-2011. Annual income threshold for poverty was $11,484 for a single person under 65 years.

Figure IV-9 shows the percentage of people of color by county. People of color includes anyone who is non-white and non-Hispanic, including black/African American, Asian, American Indian, Hawaiian/Pacific Islander, and multi-racial, or non-white and Hispanic or Latino. The highest percentage of persons of color is located in Mahnomen County, where 38% of the population is American Indian, 8% multiracial and 2% Hispanic. Other Northwestern and Northern counties including Becker, Beltrami and Cass, have high percentages of people of color, mostly American Indian. Kandiyohi, Watonwan, Nobles, Olmsted and Mower counties in Western, Southwestern and Southern Minnesota have higher percentages of people of color, mostly Hispanic or Latino. The metro area counties have over 11% people of color, with the highest percentages in Hennepin and Ramsey counties, 28% and 32%, respectively. Racial diversity is more mixed in the metro area, including higher percentages of Asians, blacks/African Americans, Hispanics or Latinos, and multiracial persons; with no single race being dominant. Persons of color in central and southern Minnesota may be more at risk for heat-related illnesses due to the greater incidence of heat event declarations.

FIGURE IV-9: PERCENT OF PEOPLE OF COLOR BY COUNTY



Data source: American Community Survey 5-year Estimates, 2007-2011.

Any condition that affects the body's ability to cool itself or puts additional stress on already compromised systems will make a person more susceptible to adverse health effects from heat. Persons with pre-existing health conditions, such as obesity, diabetes, renal failure, and liver, cardiovascular, respiratory, and neurological diseases, are more vulnerable to the effects of heat (Green et al., 2001; CDC, 2006b; Baccini et al., 2008; Kaiser et al., 2007; Vandentorren et al., 2006; Swartz, 2005). Certain medications can also reduce the body's ability to cool itself. Bedridden persons and those living in nursing homes may be at increased risk of heat-related illness due to their dependency on others for care coupled with pre-existing medical conditions or use of certain medications. Data for persons with pre-existing health conditions, persons on certain medications, and persons living in nursing homes or who are bedridden were not available for the CCVA.

People who are involved in sports or who work in outdoor occupations, including farming, landscaping, roofing, and construction, are at an increased risk of heat-related illnesses. They are exposed to the sun and extreme heat for longer periods of time and need to take extra precautions to stay cool and hydrated. Figures IV-10 and IV-11 show the percentage of workers by county that are employed in primary outdoor occupations. Workers include seasonal, part-time and full-time employees whose primary job is categorized as one of the following industries: agriculture, forestry, fishing, hunting, mining and construction.

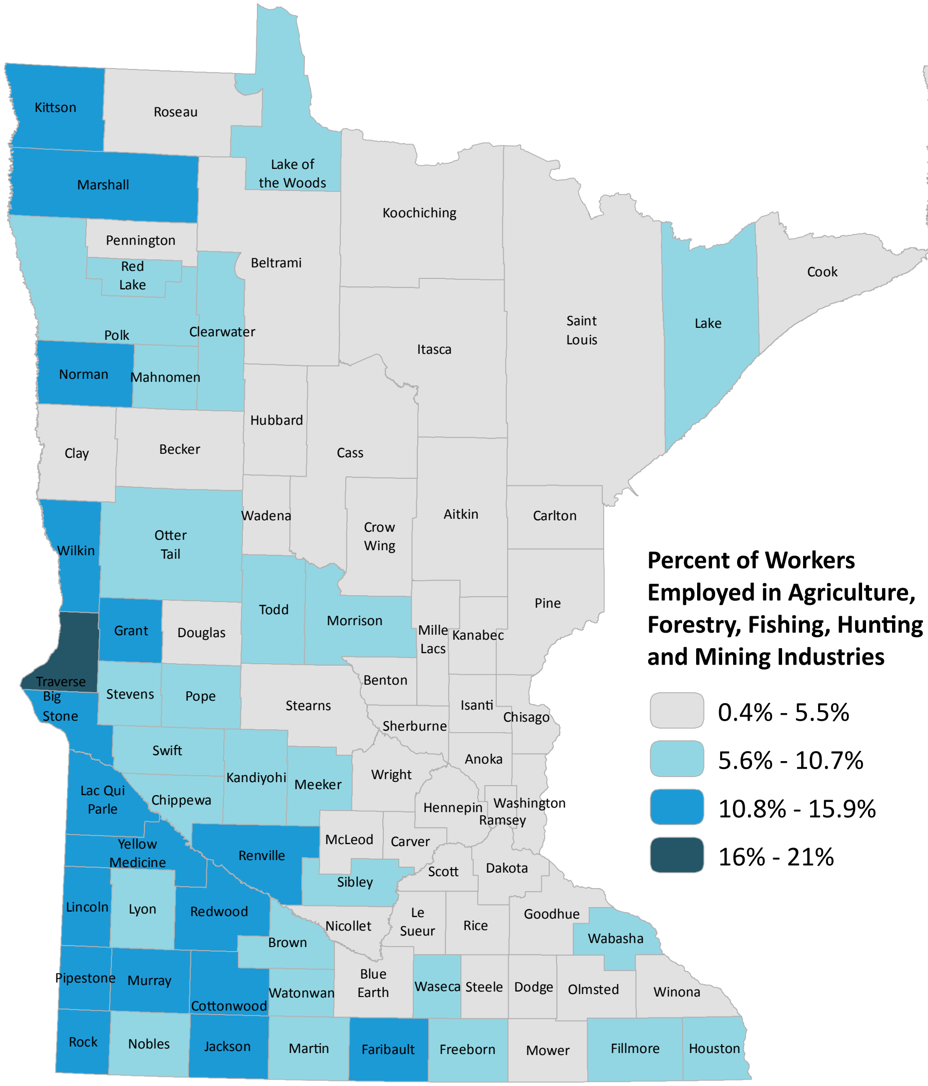
A large proportion of workers in the agricultural industry are located in west-central and southwest Minnesota where heat events occur more frequently, potentially putting them at a higher risk than outdoor workers in northern Minnesota.

A high proportion of workers in the construction industry are located in north-central Minnesota. While heat events are less likely here, construction crews may still be at risk for adverse health events on especially hot days.

These industries were selected as a proxy, representing a majority of the outdoor workforce. However, these industries also employ persons that do not work outside. For example, people employed in agriculture include truck drivers and bookkeepers. This data source does not separate outdoor from indoor workers.

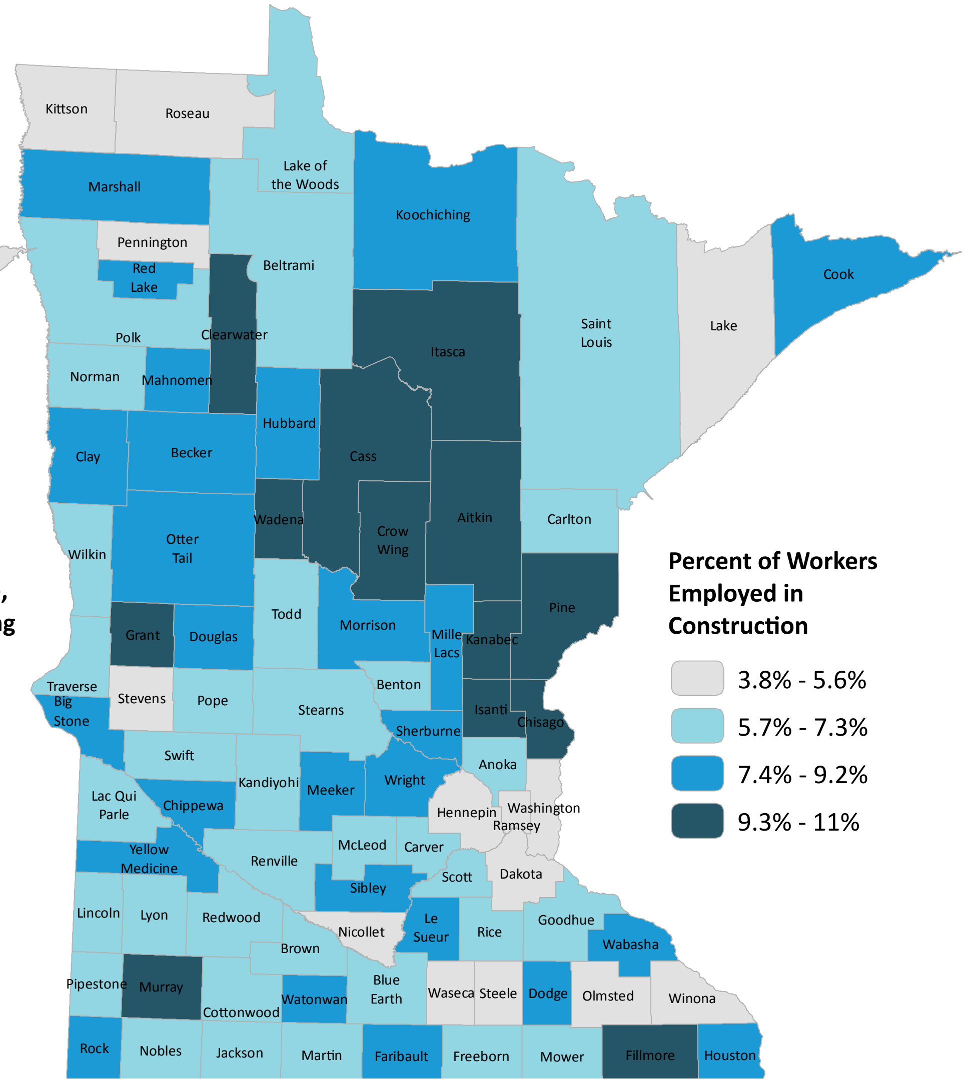
Other risk factors that increase susceptibility to heat-related illness include use of alcohol, lack of air-conditioning, and living in top-floor apartments. At the time of the analysis, data for these risk-factors were not available statewide, and therefore were not included in the CCVA.

FIGURE IV-10: PERCENT OF WORKERS EMPLOYED IN AGRICULTURE, FORESTRY, FISHING, HUNTING & MINING INDUSTRIES BY COUNTY



Data source: American Community Survey 5-year Estimates, 2007-2011

FIGURE IV-11: PERCENT OF WORKERS EMPLOYED IN CONSTRUCTION INDUSTRY BY COUNTY



Data source: American Community Survey 5-year Estimates, 2007-2011

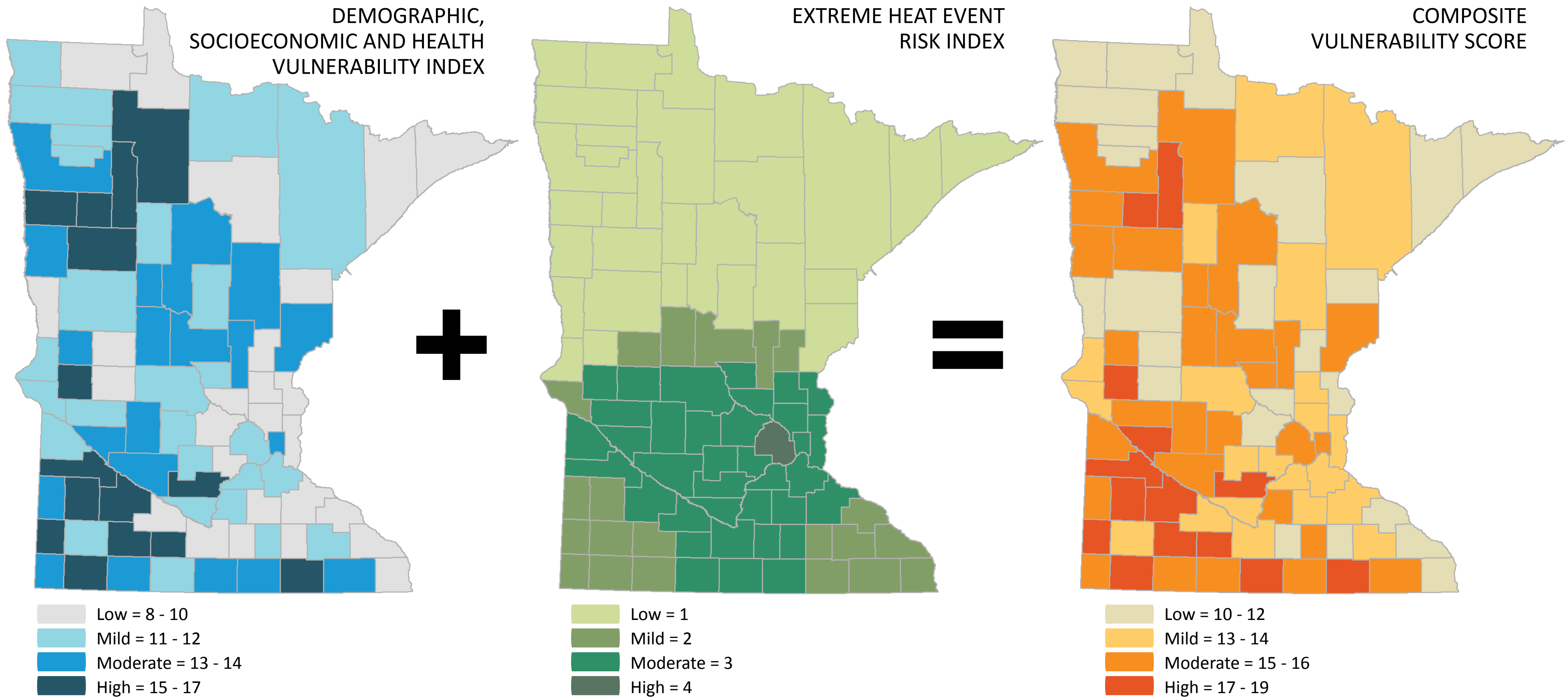
Composite Extreme Heat Vulnerability

In addition to mapping individual risk factors and vulnerabilities to extreme heat events, MDH created a composite vulnerability map for extreme heat. Figure IV-12, on the next page, combines population vulnerability with risk for extreme heat events in a composite map. The image on the far left combines the variables for population vulnerability, including: 1) population living at or below poverty, 2) older adults living alone, 3) population less than 5 years old, 4) persons of color, and 5) outdoor workers (defined as persons employed in the industries of agriculture, fishing, hunting, forestry, mining and construction). The center image provides a depiction of the risk of extreme heat events by displaying the number of past extreme heat events. The image on the right is the combination of the population vulnerability and extreme heat risk.

TABLE IV-2: COMPOSITE EXTREME HEAT VULNERABILITY SCORES BY VARIABLE

Variable	1 (Low)	2 (Mild)	3 (Moderate)	4 (High)
Proportion of children less than 5 years old	3.4 – 5.8%	5.9 – 6.4%	6.5 – 6.9%	7.0 – 9.2%
Proportion of households with adults 65 years and older living alone	5.5 – 9.9%	10.0 – 11.9%	12.0 – 14.0%	14.1 – 20.0%
Proportion of the total population living at or below poverty level	5.0 – 9.0%	9.1 – 11.2%	11.3 – 12.9%	13.0 – 26.4%
Proportion of persons of color	2.2 – 4.7%	2.8 – 7.1%	7.2 – 10.9%	11.0 – 48.6%
Proportion of workforce employed in an outdoor occupation (i.e., agriculture, forestry, fishing, hunting, mining and construction)	4.2 – 10.4%	10.5 – 13.6%	13.7 – 16.4%	16.5 – 27.7%
Number extreme heat events	0-2 heat events	3-6 heat events	7 heat events	8-9 heat events

FIGURE IV-12: POPULATION VULNERABILITY, EXTREME HEAT EVENT RISK, AND COMPOSITE HEAT VULNERABILITY MAPS



The values of each variable were ranked into quartiles and scored 1 for the first quartile to indicate the lowest vulnerability to 4 for the fourth quartile to indicate the highest vulnerability. Table IV-2, on the previous page, shows the scores and range of values for each variable. The scores for each county were summed across variables to come up with the composite score. The composite scores for all counties are displayed by quartile in Figure IV-12. No weights were applied to the variables.

Combining the occurrence of extreme heat events with socio-economic variables adds value and context to the investigation of a population's vulnerability to extreme heat. If the occurrence of extreme heat events were the only factor in determining vulnerability, then all communities in south-central Minnesota would be in the highest vulnerability category. However, due to socioeconomic variables, such as percent of population in poverty and percent of workers employed in outdoor industries, some of the south-central counties are in the lowest vulnerability category while some counties in northwestern Minnesota appear in the mild or moderate vulnerability categories. Southwestern Minnesota shows up as the highest vulnerability as a region. This index could be verified in future projects by studying the relationships between extreme temperature, socioeconomic and health variables, and heat-related illness emergency department visit and heat-related mortality data by location.

It is important to note that a low vulnerability score does not indicate that a county is not vulnerable to extreme heat. While counties with low vulnerability scores likely have lower percentages of vulnerable populations, many of the counties with low or mild vulnerability scores in the Twin Cities metro area have the highest total counts of vulnerable populations. As a result, if the composite vulnerability score had been calculated using counts instead or percentages, the results would have been drastically different. Additionally, the counties in the Twin Cities metro area and all of south-central Minnesota have experienced a larger number of extreme heat events. The value of conducting the CCVA and the composite vulnerability score is to understand that planning for climate change is more than just identifying where the risk for climate hazards exists, but also addressing how vulnerable populations will affect planning needs and community resources in the event of a climate hazard.

Effects of Climate Change on Extreme Heat

We are already seeing indications that Minnesota's climate is warming and climate change is expected to continue to increase the number of extreme heat events per summer. This overall warming pattern is affecting the number of extreme heat events per summer in a number of ways. First, daytime high temperatures are increasing; by mid-century (2041-2070) Minnesota is projected to experience five to 15 more days per summer with a maximum temperature above 95°F (Pryor et al., 2014). Second, daily minimum temperatures or overnight lows are increasing faster than daytime high temperatures, limiting the ability to cool off at night (Zandlo, 2008). Third, dew point temperatures may be increasing, which elevate the apparent temperature (heat index) and prevent sweat from evaporating off the skin, which enables the body to cool itself (Seeley, 2013). Increased maximum and minimum temperatures and dew point temperatures will likely increase the number and severity of extreme heat events in the future.

V Air Pollution

Background

Fine particle pollution (i.e., particulate matter 2.5 micrometers in diameter and smaller, "$PM_{2.5}$") and ground-level ozone are major pollutants that likely will be affected by climate change (Amann et al., 2004). Both pollutants have well established public health impacts.

Fine particle pollution includes both primary and secondary $PM_{2.5}$. Primary $PM_{2.5}$ results from direct emissions, such as combustion of fossil fuels and includes mostly elemental (black) carbon and primary organic aerosols. Secondary $PM_{2.5}$ is formed in the atmosphere from precursor emissions, such as volatile organic compounds (VOCs), sulfur dioxide (SO_2), nitrogen oxides (NOx) and ammonia gases (U.S. EPA, 2013a). Primary $PM_{2.5}$, VOCs, SO_2 and NOx are emitted in larger quantities in urban areas, mostly as a result of vehicle emissions, other mobile sources emissions, electric utilities or industrial processes (U.S. EPA, 2013a). Ammonia is the only precursor with larger emissions in rural areas than in urban areas. This is due to the large concentration of agricultural activities in rural areas where ammonia forms from the breakdown of fertilizers and animal waste and then reacts with atmospheric nitric and sulfuric acids to form $PM_{2.5}$ (Hristov, 2011). Farm and livestock operations can contribute up to 20% of $PM_{2.5}$ concentration in agricultural areas, especially in cooler weather months (Hristov, 2011).

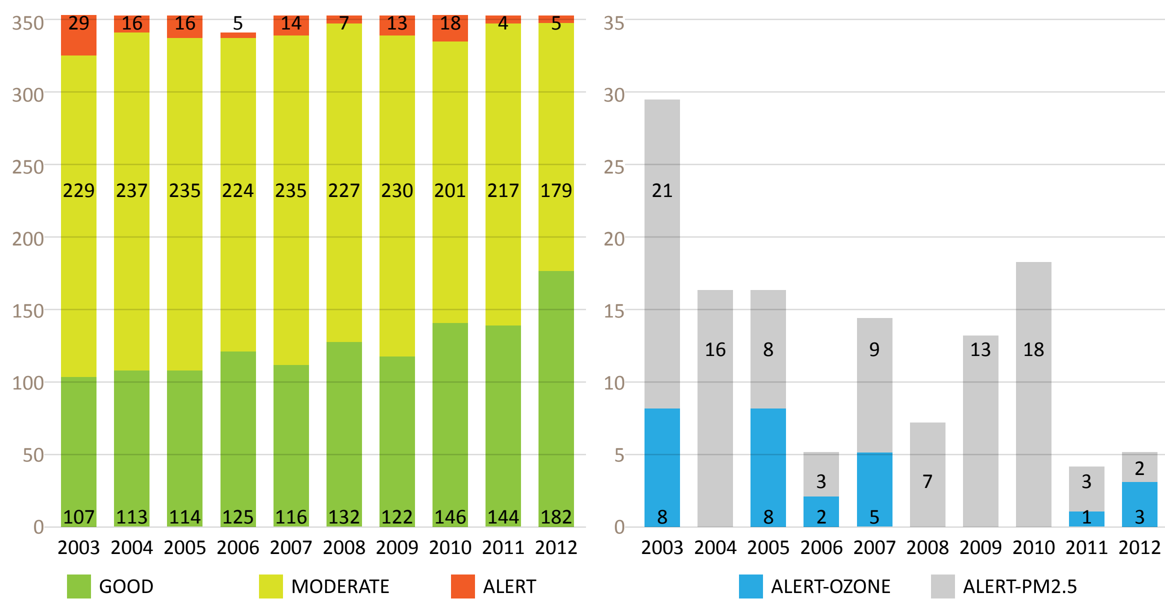
Ozone is a gas that occurs both in the Earth's upper atmosphere and at ground level. Atmospheric ozone protects life on Earth from the sun's harmful ultraviolet (UV) rays. Conversely, ground level ozone is harmful to human health and vegetation. Ground-level ozone is formed by the reaction of VOCs and NOx in the presence of sunlight and heat (U.S. EPA, 2003). Ozone is a pollutant that is generally a concern for Minnesotans in the summer months. Precursor emissions for ozone and secondary $PM_{2.5}$ are the same. In the presence of sunlight and heat the precursor emissions are more likely to form ozone in the summer time and in the winter are more likely to form secondary $PM_{2.5}$ (personal communication, Margaret McCourtney, Minnesota Pollution Control Agency, June 3, 2013).

$PM_{2.5}$ can have serious health impacts, including significant increases in mortality from cardiovascular and cardiopulmonary diseases, as well as cancer (Pope et al., 2002). Acute exposure to fine particle pollution exacerbates respiratory illness and increases the numbers of hospitalizations and deaths from cardiovascular and respiratory diseases (Pope, 2000; Bernard et al., 2001). Long-term effects on health, particularly in older adults and children, include impaired respiratory function, chronic cough, bronchitis, chest illness, and increased risk for respiratory conditions, such as chronic obstructive pulmonary disease (COPD), pneumonia, and cardiovascular disease (Pope, 2000). Long-term exposure to fine particle pollution is associated with cardiopulmonary and lung cancer mortality (Pope et al., 2002; Bernard et al., 2001).

The health effects of concern for ground-level ozone relate primarily to lung inflammation (Bernard et al., 2001). Short-term exposure of healthy individuals (including children) to elevated levels of ozone concentrations can cause respiratory conditions and cardiopulmonary impacts, including lung irritation, breathing difficulties, reduced lung capacity, aggravated asthma and COPD, and increased susceptibility to bronchitis (Bernard et al., 2001; Tager et al., 2005). Long-term exposure is suspected to contribute to the development and exacerbation of chronic lung diseases by causing permanent changes in the airways and alveoli and accelerating lung function decline (Tager et al., 2005). It may also contribute to new-onset asthma in children (Islam et al., 2009; McConnell et al., 2002).

Overall in the U.S., air quality has been improving in recent years. From 2001 to 2012, ground-level ozone is 13% lower, short-term particulate pollution is 28% lower and year-round particulate pollution is 24% lower (ALA, 2012). However, 41% of U.S. population lives in counties that have unhealthy levels of either ground-level ozone or particulate pollution (ALA, 2012). Recent studies demonstrate that negative health impacts can occur at lower levels of air pollutants than previously thought and below regulatory levels (Crouse et al., 2012; Dales et al., 2009; Medina-Ramon et al., 2006).

FIGURE V-1: AQI AND AIR QUALITY ALERT DAYS IN THE TWIN CITIES



Source: Minnesota Air Quality Index Trends 2003 – 2012, Minnesota Pollution Control Agency.

Air Quality in Minnesota

The Minnesota Pollution Control Agency (MPCA) monitors $PM_{2.5}$ and ozone concentrations for the state and calculates the Air Quality Index (AQI). MPCA announces air quality alerts when pollution levels become unhealthy. The AQI is an index developed by the U.S. Environmental Protection Agency (U.S. EPA) to provide a simple, uniform way to report daily air quality conditions (MPCA, 2013). Recent records of the AQI and air quality alert days in Minnesota suggest improvements in overall air quality.

See Figure V-1 for monitored data in the Twin Cities from 2003 through 2012. Despite consistent improvement in the number of "good" air quality days, there remains significant year to year variability in the number of poor air quality days. Much of the variation can be attributed to weather and climate variability (MPCA, 2013).

FIGURE V-2: FINE PARTICLE POLLUTION IN MINNESOTA

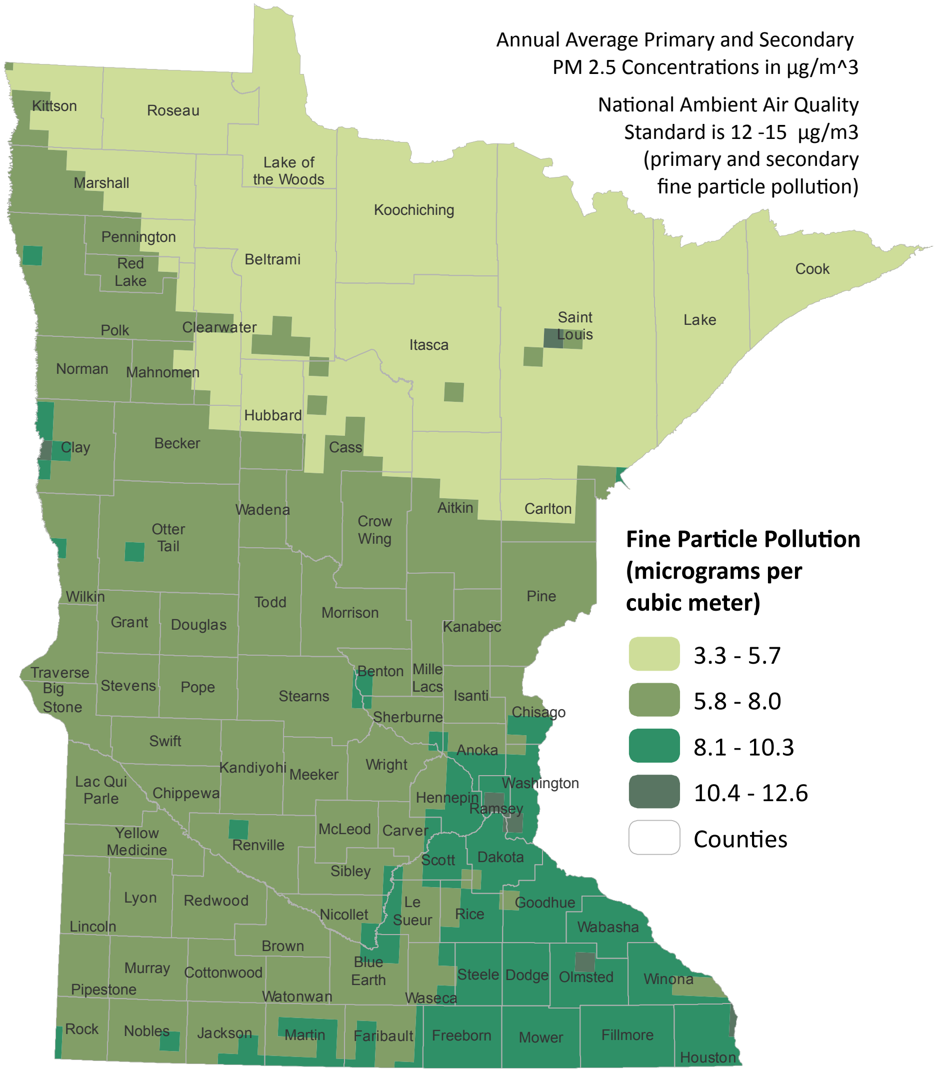


Figure V-2 shows the spatial variation of modeled annual average concentrations of $PM_{2.5}$ in micrograms per cubic meter (µg/m3) for 12km grid volumes across the state of Minnesota.[1] The map shows higher concentrations of $PM_{2.5}$ in the 7-county metro area and southeastern Minnesota. This is a result of higher localized primary and secondary $PM_{2.5}$ emissions from the metro area as well as transport of secondary $PM_{2.5}$ from the Midwest and Lake Michigan area (personal communication, Margaret McCourtney, Minnesota Pollution Control Agency, June 3, 2013).

The National Ambient Air Quality Standard (NAAQS) established by the United States Environmental Protection Agency (U.S. EPA) in 2012 for annual average fine particle pollution is 12 µg/m3 (U.S. EPA, 2013b). The maximum measured concentration of particle pollution in Minnesota was 10.7 µg/m3 for 2006-2008 and 9.7 µg/m3 for 2010-2012, both below the NAAQS (personal communication, Margaret McCourtney, Minnesota Pollution Control Agency, June 3, 2013).

1 The concentrations are derived by using a chemical transport model (CAMx) for the base year 2007 and fusing that output with monitoring data from 2006-2008. The Voronoi Neighbor Averaging technique was used in the fusing, where the model values provide the spatial gradient. The concentration values are provided for 12km grid volumes. Model was run by the Minnesota Pollution Control Agency.

Figure V-3 shows the modeled average concentrations of ground-level ozone in parts per billion (ppb) for 12km grid volumes during the months of April through October.

Higher concentrations of ground-level ozone are formed in a ring surrounding the urban core of Minneapolis-St. Paul, as well as slightly higher concentrations surrounding other urban areas in Minnesota. This is a result of the "titration" effect "in which ozone is destroyed by reactions with the high levels of nitric oxide (NO) in the center of an urban area. The highest ozone levels occur downwind from the urban center where the ozone-generating reactions have had time to occur" (personal communication, Gregory Pratt, Minnesota Pollution Control Agency, February 13, 2013). The NAAQS for ozone is based on an annual fourth-highest maximum 8-hour concentration averaged over 3 years, not the seasonal average demonstrated in Figure V-3. The NAAQS for ozone is 75 ppb (U.S. EPA, 2013b). In Minnesota, the measured annual fourth-highest maximum 8-hour ozone concentration for 2006-2008 was 69 ppb, and 67 ppb for 2010-2012, both below the NAAQS (personal communication, Margaret McCourtney, Minnesota Pollution Control Agency, June 3, 2013).

Figures V-4 and V-5, demonstrate the annual average number of days that exceed the NAAQS for $PM_{2.5}$ and ozone. County data was created by EPA using the Downscaler modeled predictions for counties and days without monitoring data and using Air Quality System data for counties and days with monitoring data. The two figures show that statewide on average there are no more than three days that exceed the NAAQS for either ozone or $PM_{2.5}$. The counties experiencing the highest number of poor air quality days are similar to those with higher average annual pollution levels, demonstrated in Figures V-2 and V-3.

Currently, the daily NAAQS for $PM_{2.5}$ is 35.0 µg/m3 and the daily NAAQS for ozone is 75 ppb. The EPA is in the process of reviewing the NAAQS based on continuing research that shows negative health outcomes related to lower levels of pollution. They may lower the daily values as soon as the end of 2014 or early 2015. Lowering the NAAQS could put more counties in Minnesota in non-attainment.

FIGURE V-3: AVERAGE SUMMER OZONE CONCENTRATIONS

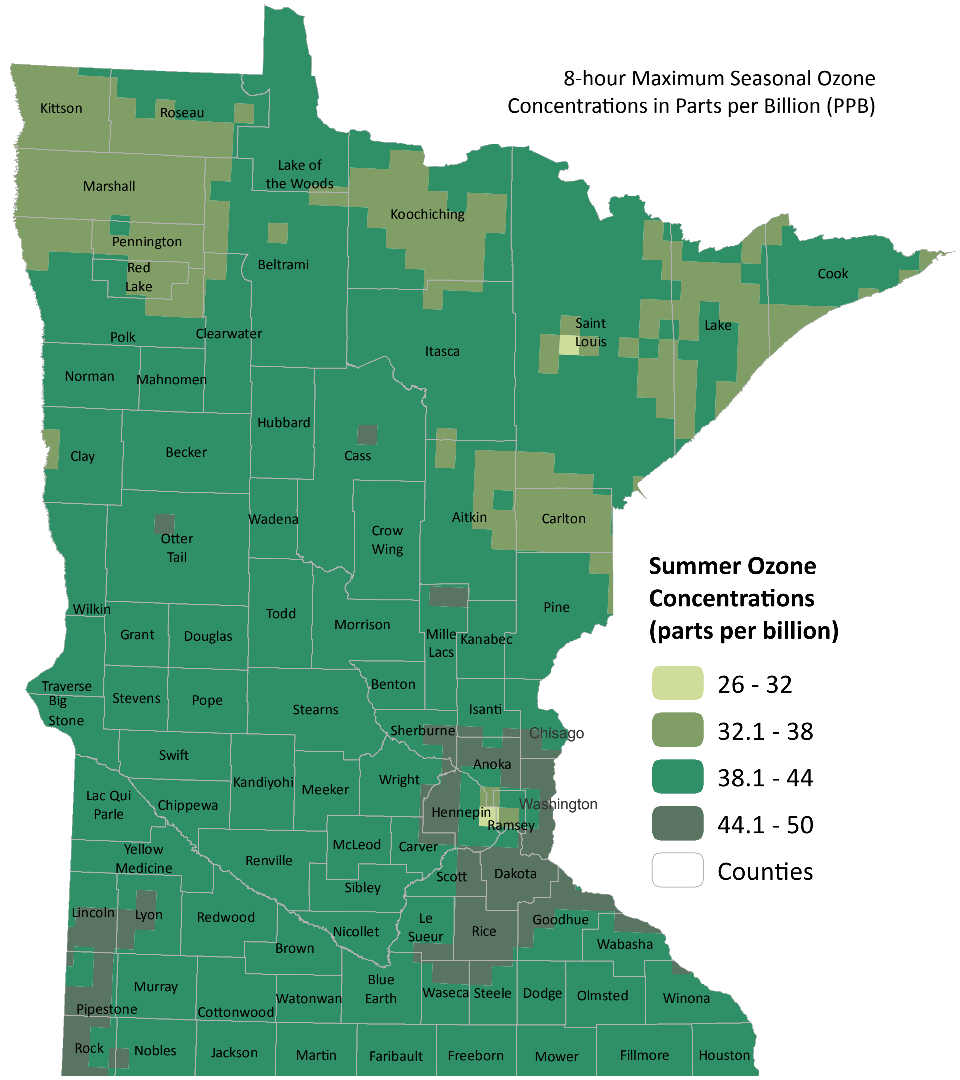
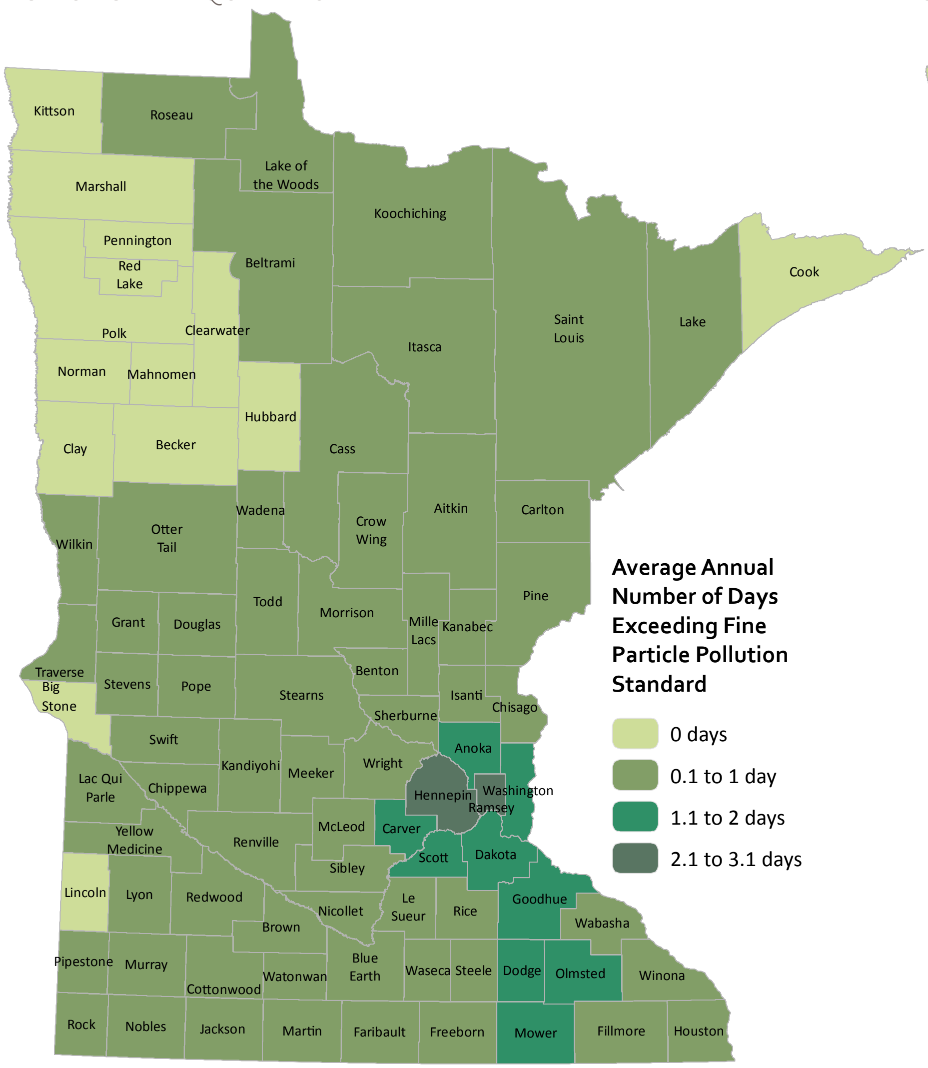
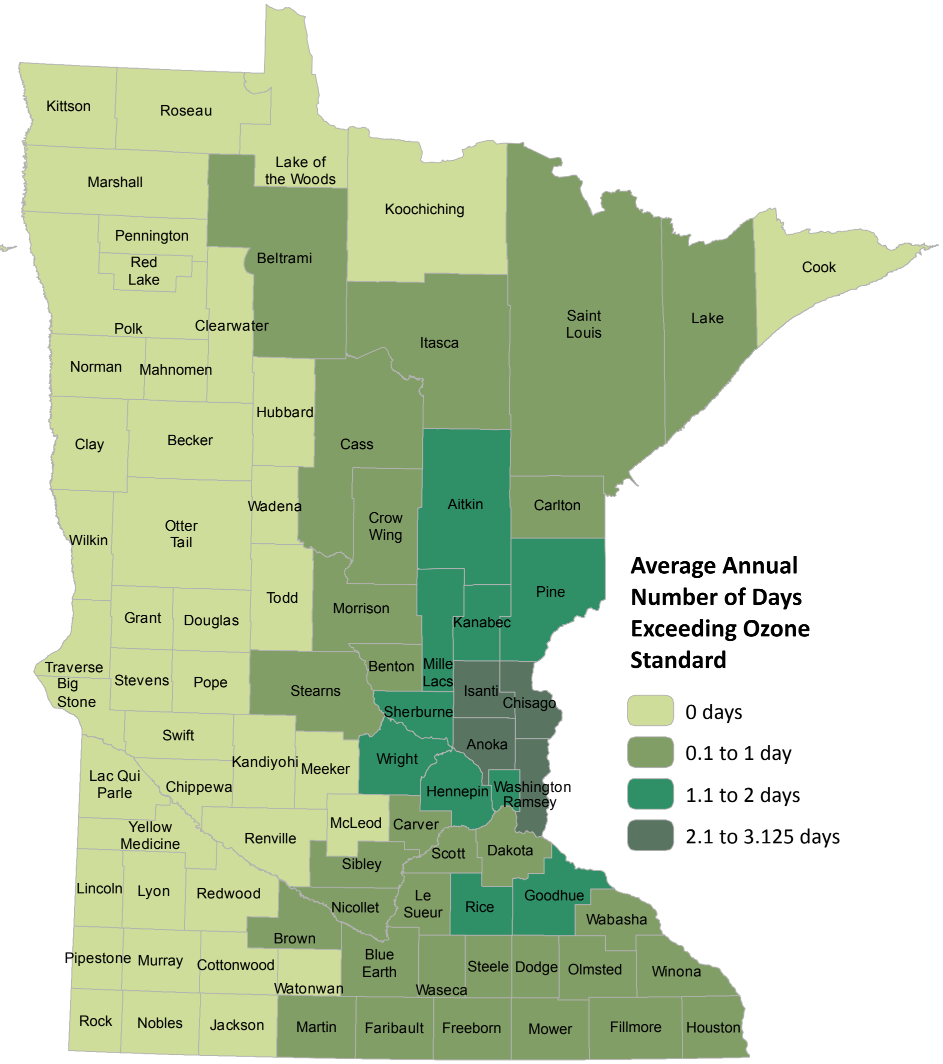


FIGURE V-4: AVERAGE ANNUAL DAYS EXCEEDING FINE PARTICLE POLLUTION AIR QUALITY STANDARD



Data source: CDC National Environmental Public Health Tracking Network

FIGURE V-5: AVERAGE ANNUAL DAYS EXCEEDING OZONE AIR QUALITY STANDARD



Data source: CDC National Environmental Public Health Tracking Network

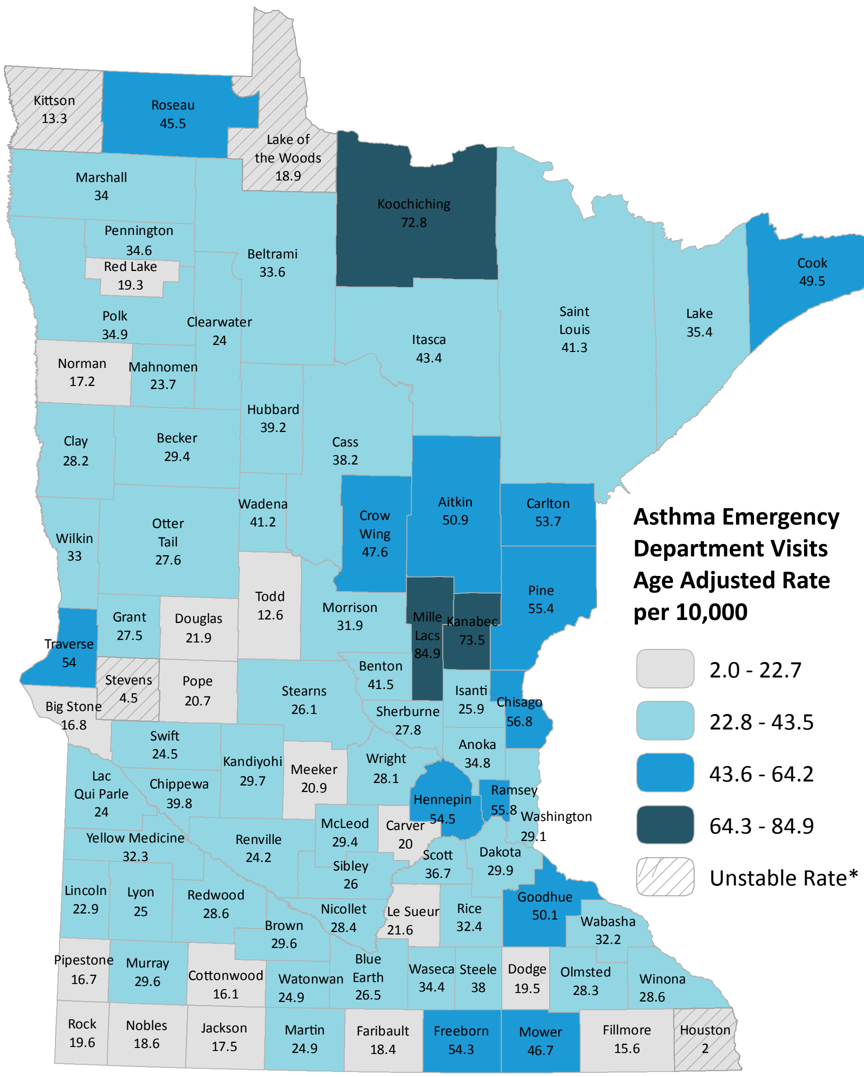
Populations Vulnerable to Poor Air Quality

Populations vulnerable to the negative health effects from particle pollution and ozone include young children, older adults, persons of color and persons with existing cardiovascular or respiratory diseases, such as asthma or COPD (Bernard et al., 2001; U.S. EPA, 2006). Children, outdoor workers and exercisers are more at risk because of their increased time outside exposed to ozone, as well as, their more rapid breathing rate. Maps presented in the previous section showed the distribution of older adults (Figure IV-5), children less than five years old (Figure IV-7), and outdoor workers (Figures IV-10 and IV-11).

Populations of color, particularly African Americans and American Indians, have higher prevalence of respiratory disease, such as asthma, higher asthma mortality rates, higher COPD mortality rates, higher rates of lung cancer, and higher rates of cardiovascular disease mortality (Brown et al. 2003; Mannino et al., 2002; NHLBI Working Group, 1995; MSS, 2010; MDH, 2014a; CBCF, 2004). Additionally, persons of color are more likely to be living near sources of air pollution (Lopez, 2002; CBCF, 2004). Figure IV-9 in the previous sections depicts the distribution of persons of color in Minnesota.

Figures V-6 and V-7 show asthma emergency department (ED) visits and hospitalization rates, respectively, by county. Figure V-8 shows COPD hospitalization rates by county. Mille Lacs, Benton and Kanebec counties consistently had higher age-adjusted rates of asthma ED visits, asthma hospitalizations and COPD hospitalizations. Mille Lacs had the highest age-adjusted rate for asthma ED visits (84.9 per 10,000 persons in the population) and the second highest age-adjusted rate for both asthma (12.8 per 10,000) and COPD (78.2 per 10,000) hospitalizations. Benton had the highest age-adjusted rate of asthma hospitalizations (13.3 per 10,000), and Clearwater had the highest age-adjusted rate of COPD hospitalizations (90.8 per 10,000).

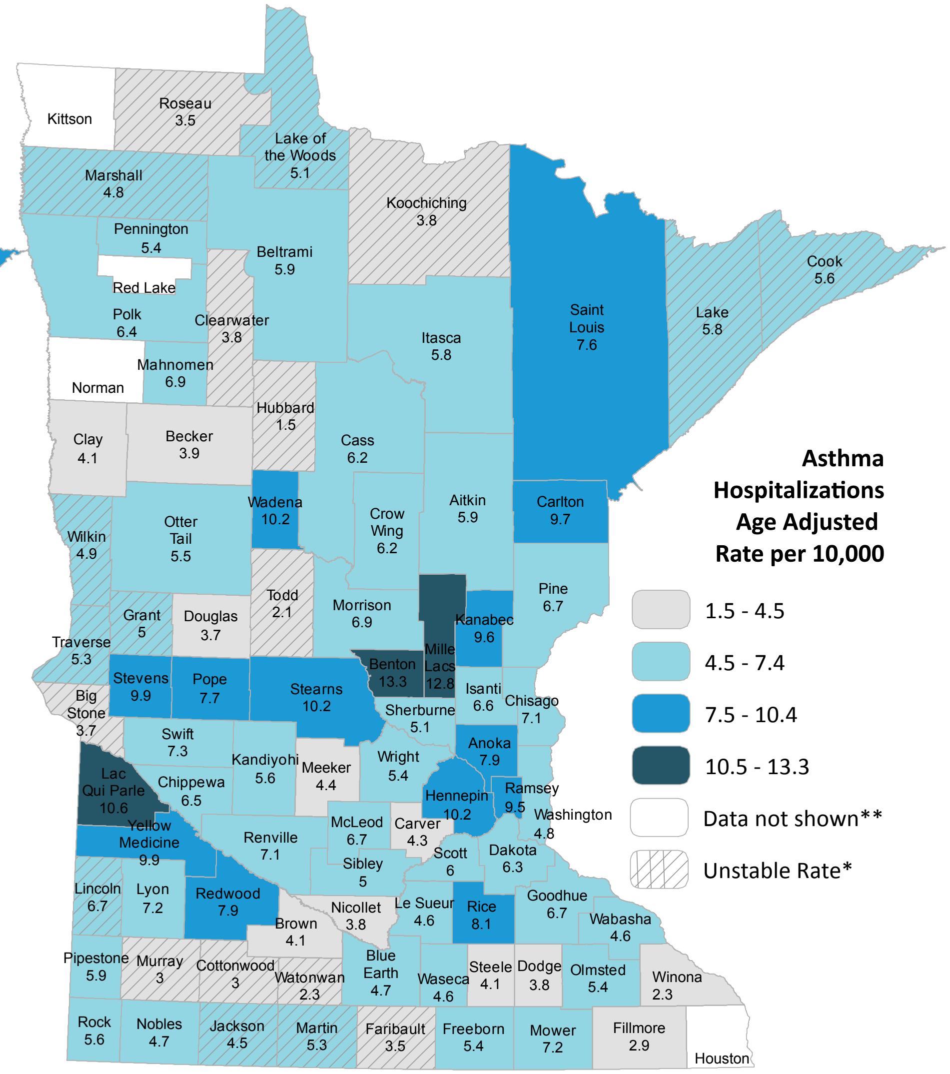
FIGURE V-6: ASTHMA EMERGENCY DEPARTMENT VISITS



*Rates based on counts of 20 or less are flagged as unstable and should be interpreted with caution. These rates are unstable because they can change dramatically with the addition or subtraction of one case.

Data source: Minnesota Environmental Public Health Tracking (MN EPHT) Program

FIGURE V-7: ASTHMA HOSPITALIZATIONS BY COUNTY



*Rates based on counts of 20 or less are flagged as unstable and should be interpreted with caution. These rates are unstable because they can change dramatically with the addition or subtraction of one case.

**To protect an individual's privacy, counts from 1 to 5 and rates based on counts from 1 to 5 are suppressed if the underlying population is less than or equal to 100,000.

Data source: Minnesota Environmental Public Health Tracking (MN EPHT) Program

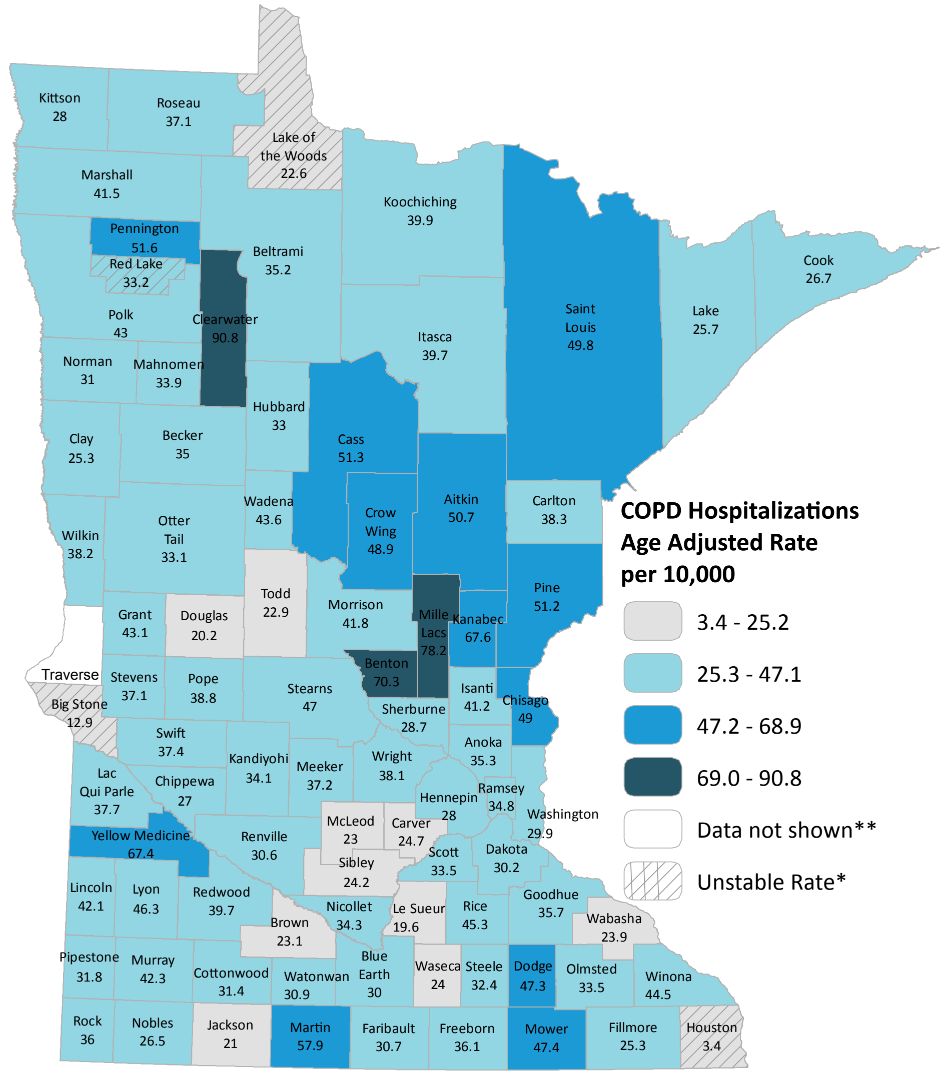
In terms of absolute burden, the highest total count of asthma ED visits, asthma hospitalizations and COPD hospitalizations combined occurred in Hennepin County, followed by Ramsey, Dakota and Anoka counties, due to the larger populations in the metropolitan counties. St. Louis County had the third highest count of COPD hospitalizations, after Hennepin and Ramsey counties.

Ozone and $PM_{2.5}$ levels are generally low in Greater Minnesota, with one or maybe two days per year that the NAAQS is exceeded. Ozone and $PM_{2.5}$ levels are higher in the metro area; however, only two to three days per year exceed the daily NAAQS. The difference in the number of days that the NAAQS is exceeded in Greater Minnesota versus the metro area is primarily a result of the difference in concentration of persons, transportation infrastructure, and industry, which contribute to pollution emissions.

Persons with respiratory disease, children and older adults should take certain precautions on air quality alert days, such as minimizing the amount of time spent near high-emitting pollution sources (i.e., busy roadways, idling vehicles, construction equipment, recreational fires, etc.) and rescheduling activities to hours in the day when pollutant levels are lowest (morning hours for ozone) or adjusting activities to reduce the duration or intensity of the activity.

Agricultural workers are predominantly located in western Minnesota where ozone and $PM_{2.5}$ levels exceed the NAAQS less than 1 day per year on average. There are higher percentages of construction workers in north-central Minnesota counties where ozone and $PM_{2.5}$ concentrations exceed the NAAQS one to two days per year on average. Outdoor workers should be cautious about their activity on air quality alert days.

FIGURE V-8: CHRONIC OBSTRUCTIVE PULMONARY DISEASE (COPD) HOSPITALIZATIONS BY COUNTY

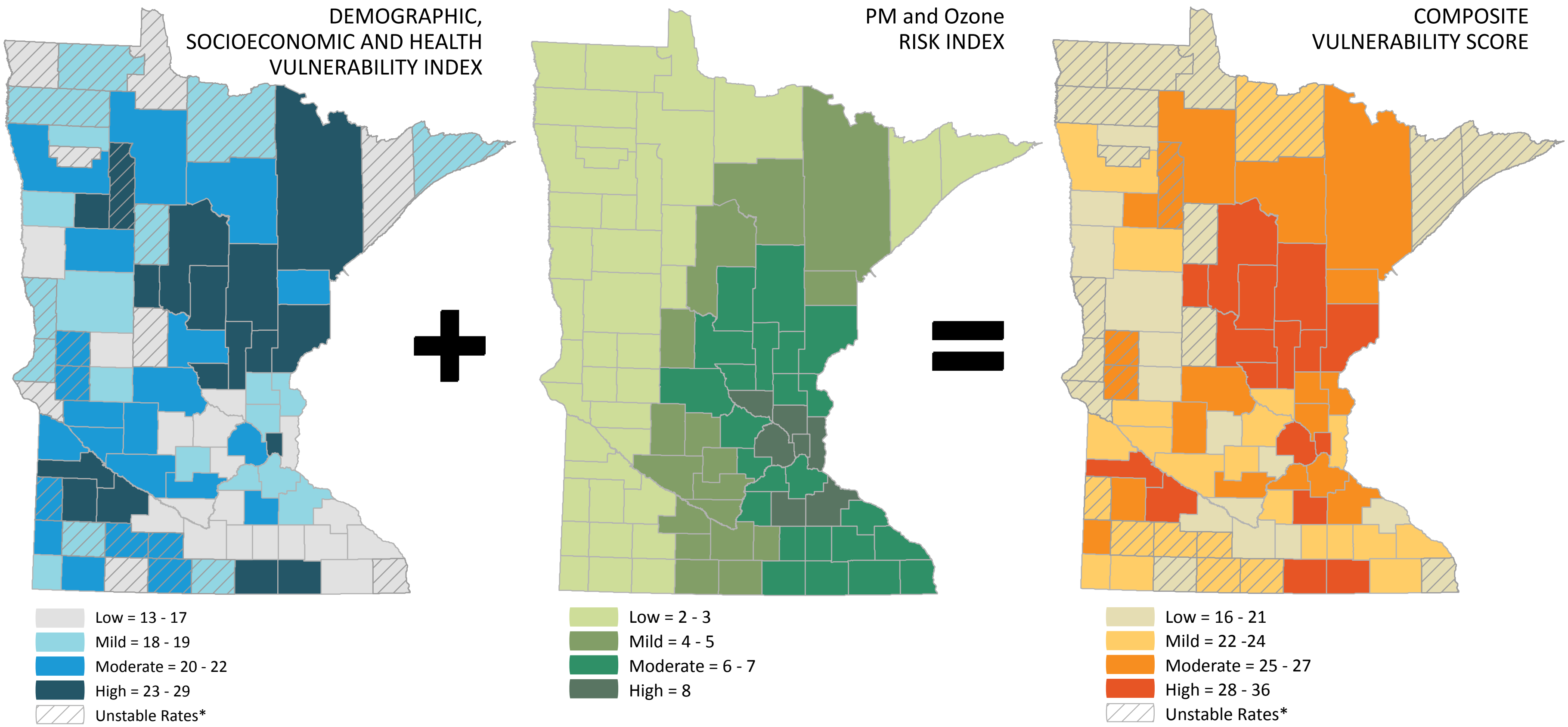


*Rates based on counts of 20 or less are flagged as unstable and should be interpreted with caution. These rates are unstable because they can change dramatically with the addition or subtraction of one case.

**To protect an individual's privacy, counts from 1 to 5 and rates based on counts from 1 to 5 are suppressed if the underlying population is less than or equal to 100,000.

Data source: Minnesota Environmental Public Health Tracking (MN EPHT) Program

FIGURE V-9: POPULATION VULNERABILITY, AIR QUALITY RISK, AND COMPOSITE AIR QUALITY VULNERABILITY MAPS



*One or measure has an unstable rate. Rates based on counts of 20 or less are flagged as unstable and should be interpreted with caution.

Composite Air Quality Vulnerability

Figure V-9 combines the health, socio-economic and employment data with air quality alert days in a composite air quality vulnerability index. The image on the far left combines the variables for population vulnerability, including: 1) asthma emergency department visit rates, 2) asthma hospitalization rates, 3) COPD hospitalization rates, 4) young children less than 5 years old, 5) older adults 65 years old and older, 6) population living at or below the poverty level, 7) persons of color, and 8) workers employed in outdoor occupations. The center image combines the variables for the climate hazard, including the number of days exceeding the NAAQS for both ozone and particle pollution. The image on the right is the combination of the population vulnerability and climate hazard risk. The values of each variable were ranked into quartiles and scored 1 for the first quartile to indicate the lowest vulnerability to 4 for the fourth quartile to indicate the highest vulnerability. Table V-1 shows the scores and range of values for each variable.

The scores for each county were summed across variables to come up with the population vulnerability, climate hazard risk, and composite scores. The scores for all counties are displayed by quartile in Figure V-9. No weights were applied to the variables. However, asthma ED rates and asthma

TABLE V 1: COMPOSITE AIR QUALITY VULNERABILITY SCORES BY VARIABLE

Variable	1 (Low Vulnerability)	2 (Mild Vulnerability)	3 (Moderate Vulnerability)	4 (High Vulnerability)
Asthma emergency department visit rate per 10,000 by county	2.0 – 22.9	23.0 – 29.1	29.2 – 39.2	39.3 – 84.9
Asthma hospitalization rate per 10,000 by county	1.5 – 4.4	4.5 – 5.6	5.7 – 7.1	7.2 – 13.3
COPD hospitalization rate per 10,000 by county	3.4 – 28.7	28.8 – 35.3	35.4 – 43.0	43.1 – 90.8
Proportion of population less than 5 years old by county	3.4 – 5.8%	5.9 – 6.4%	6.5 – 6.9%	7.0 – 9.2%
Proportion of population 65 years old and older by county	7.5 – 13.6%	13.7 – 17.1%	17.2 – 19.9%	20.0 – 26.8%
Proportion of the population living at or below poverty level	5.0 – 9.0%	9.1 – 11.2%	11.3 – 12.9%	13.0 – 26.4%
Proportion of persons of color	2.2 – 4.7%	4.8 – 7.1%	7.2 – 10.9%	11.0 – 48.6%
Proportion of workforce employed in an outdoor occupation (i.e., agriculture, forestry, fishing, hunting, mining and construction)	4.2 – 10.4%	10.5 – 13.6%	13.7 – 16.4%	16.5 – 27.7%
Average number of days exceeding NAAQS for ozone 2001-2008	0 days	> 0 – 0.5 days	> 0.5 – 1.1 days	> 1.1 – 3.1 days
Average number of days exceeding NAAQS for particle pollution 2001-2008	0 – 0.1 days	> 0.1 – 0.5 days	> 0.5 – 0.8 days	> 0.8 – 3.1 days

hospitalization rates do overlap – that is, ED visits resulting in admission to the hospital are counted in both the ED visit and the hospitalization rates. As a result, ED visits are inherently given more weight in the composite measure.

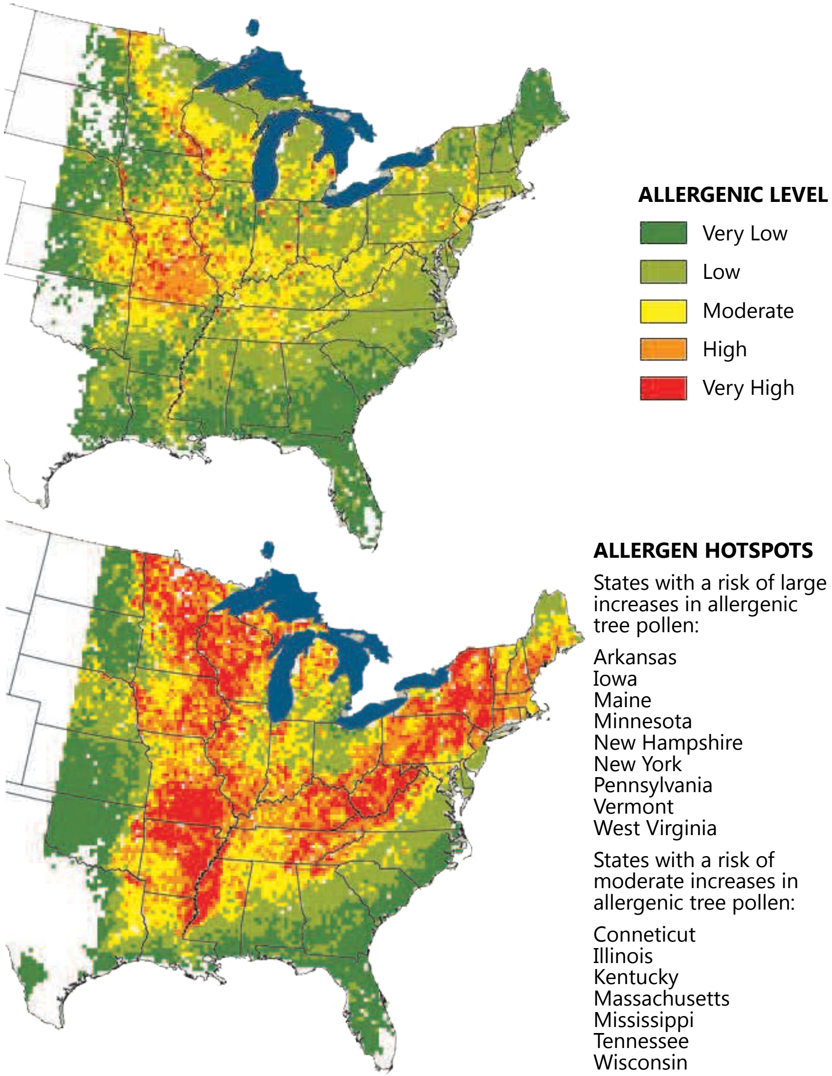
Figure V-9 demonstrates how the relative proportion of vulnerable populations in a county can impact a county's overall assessment of vulnerability to poor air quality. For example, many of the counties in southwest Minnesota, such as Yellow Medicine, Lyon and Redwood, experienced zero or one days exceeding air quality standards, however the composite vulnerability scores calculated for these counties were in the highest and second highest quartiles as a result of the range of health, socio-economic and employment characteristics relevant to these counties. Conversely, Carver County experienced a moderate presence of poor air quality, but is in the lowest quartile for vulnerability when health, socio-economic and employment characteristics are accounted for.

Pollen

Allergens, such as pollen and mold, are affected by changes in weather and climate and can negatively impact health. Allergens cause mild to severe allergic reactions ("allergies") in millions of Americans. Approximately 25 million Americans suffer from hay fever (allergic rhinitis) alone (NWF, 2010). Increased summer ozone and $PM_{2.5}$ levels can exacerbate allergies, amplifying the individual effects of allergens (Parker et al., 2009).

A recent study based on data collected from various Midwest pollen stations for the period 1995-2013 revealed that the ragweed pollen season has increased by as much as 15 to 21 days for areas in and around Minnesota (Ziska et al., 2014). Monitored allergen data is available for Minneapolis going back to 1993. The data comes from the Clinical Research Institute, the only American Academy of Allergy Asthma and Immunology certified pollen monitor in Minnesota.

FIGURE V-10: ANNUAL ALLERGENIC TREE POLLEN POTENTIAL: 2010 AND 2100



Source: National Wildlife Federation, 2010, Extreme Allergies and Global Warming
http://www.nwf.org/extremeweather

In 2010, the National Wildlife Federation produced a study that projected the risk of increases in allergenic tree pollen for the Midwest, Northeast and Southeast regions of the U.S. in 2100. Figure V-10 shows that as of 2010 there was low to moderate risk of allergenic pollen throughout Minnesota, but by 2100 the majority of the state will experience moderate to very high risk.

Effects of Climate Change on Air Quality

Climate change may have negative effects on air quality. Increases in temperatures and air stagnation events are likely to cause negative impacts on air quality. Warmer summer temperatures may both increase the natural emission of VOCs from plants and vegetation (Bernard et al., 2001), and catalyze the process of ozone formation (Jacob & Winner, 2009; Bernard et al., 2001). Warmer spring and summer temperatures also are driving a lengthening of the allergy season, an increase in allergenic pollen plants, and increases in the potency of allergenic pollen (Rogers et al., 2006; Jacob & Winner, 2009; Bernard et al., 2001). Increased temperatures may increase $PM_{2.5}$ as a result of more fossil fuel combustion to meet electricity demand for increased air conditioner use.

Climate change also may increase the frequency of air stagnation events, which allow pollutants to hover and create poor air quality (Jacob & Winner, 2009; Wu et al., 2008). The worst air pollution days often occur during air stagnation events when there is no wind to blow away pollutants. Stagnant air events occur both in summer and winter, causing air quality alert days for ozone and fine particle pollution, respectively. Ultimately, pollution emission reductions are necessary for continued improvement in ambient air quality.

VI Vector-borne Disease


Adult deer tick, *Ixodes scapularis*. Image courtesy of Wikimedia Commons

Background

Vector-borne diseases are diseases transmitted to humans and animals by ticks, mosquitoes, or other insects (i.e., vectors) that carry pathogens that cause disease. The most prominent vector-borne diseases in Minnesota include Lyme disease, human anaplasmosis, and West Nile virus (MDH, 2013a).

Lyme disease is a potentially serious bacterial infection caused by the bite of an infected blacklegged tick (also known as the deer tick) (MDH, 2013b). An infected tick must be attached to a person for 24-72 hours to transmit the bacteria (Piesman et al., 1987). Early symptoms of Lyme disease include fever, chills, headache, muscle and joint pain, and fatigue, as well as a distinctive "bulls eye" rash that begins as a reddened area near the tick bite. Long-term effects of Lyme disease can include arthritis, problems with the nervous system, and persistent weakness and fatigue.

Human anaplasmosis (HA) is the second-most commonly reported tick-borne disease in Minnesota after Lyme disease (MDH, 2013c). HA also is a bacterial disease transmitted to humans by blacklegged ticks. Signs and symptoms of HA may include high fever (over 102° F), severe headache, muscle aches, chills and shaking. Severe complications can include respiratory failure, renal failure and secondary infections (MDH, 2013c).

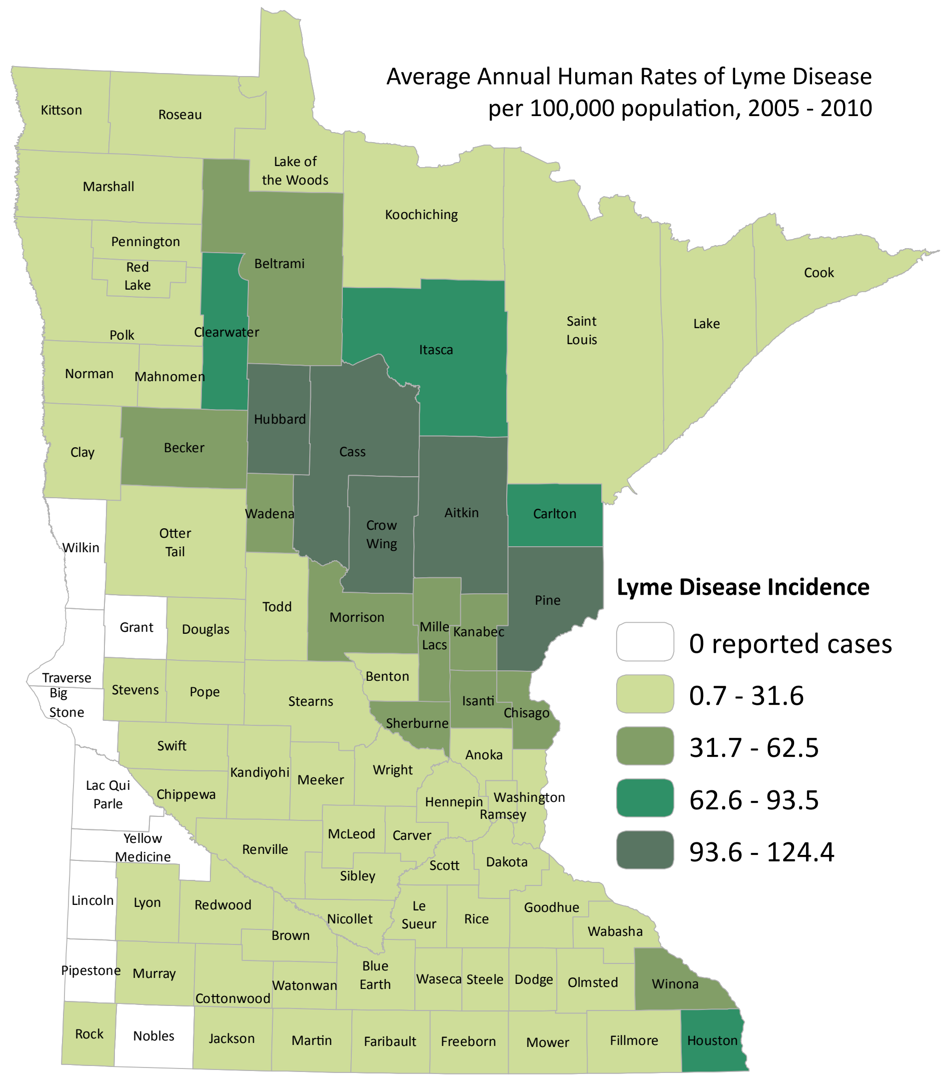
West Nile virus (WNV) is transmitted to people and horses through the bite of an infected mosquito (MDH, 2013d). Most people infected with WNV will have either no symptoms or a very mild illness. Symptoms of WNV can be similar to the flu; severe cases may include sudden onset of fever, headache, stiff neck, and vomiting. A few people, mainly older adults, may develop encephalitis (inflammation of the brain) which is fatal in approximately 10% of the encephalitis cases (MDH, 2013d).

Vector-borne Disease in Minnesota

The vast majority (80%) of tick-borne disease cases in Minnesota are Lyme disease. Since 2004, over 900 Lyme disease cases have been reported each year, with a record number of 1,293 confirmed cases reported in 2010 (MDH, 2013e). According to MDH Lyme disease statistics, "the number of Lyme disease cases has been increasing dramatically since the 1990s. A variety of factors, including increasing physician awareness, increasing infection rates in ticks, and expanding tick distribution may have led to this trend" (MDH, 2013e).

Figure VI-1 shows the average annual Lyme disease rates per 100,000 persons by county for 2005 through 2010. It is important to note that incidence is attributed to the county of residence, which may be different from the county in which the disease was acquired. The counties with highest annual average rates of Lyme disease are in north-central Minnesota where forested habitat for blacklegged ticks is optimal. The county with the highest rate of Lyme disease was Crow Wing County in 2007 with approximately 181 per 100,000 residents (111 total cases). From 2005-2010, the largest number of cases has occurred in residents of Hennepin County and the metro area. This could be a result of metro area residents traveling to the northern woods and contracting the disease, or the spread of blacklegged ticks into metropolitan areas (Lee et al., 2013). The year with the largest number of cases in Hennepin County residents was 2007 with 195 cases and a rate of approximately 17 per 100,000.

FIGURE VI-1: LYME DISEASE INCIDENCE 2005 - 2010

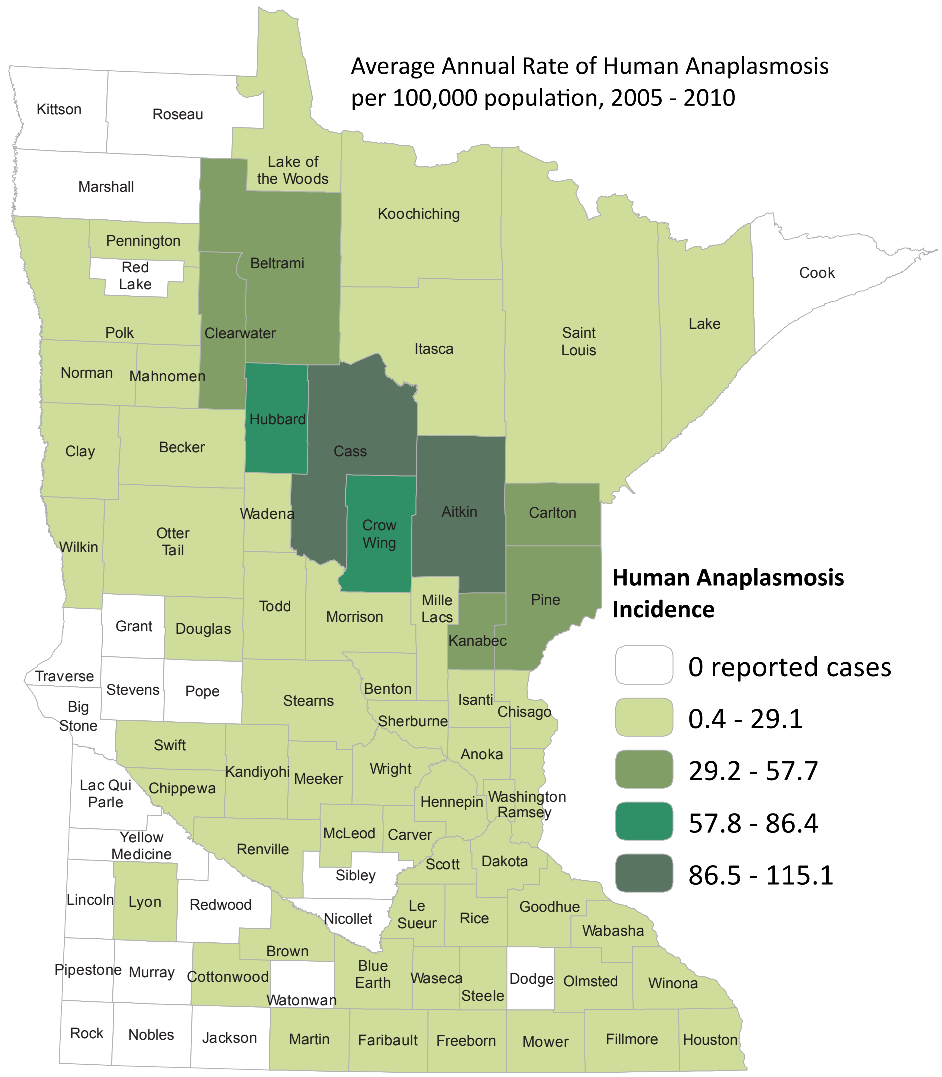


Data source: Minnesota Department of Health, Acute Disease Investigation and Control, 2011

HA was first recognized during 1993 in several patients from Minnesota and western Wisconsin (MDH, 2013c). The number of HA cases has been increasing sharply since the first cases of HA were reported in Minnesota in the mid-1990s. Similar to Lyme disease reporting, a variety of factors, including increasing physician awareness, increasing infection rates in ticks, and expanding tick distribution, may have led to this trend (MDH, 2013c).

Figure VI-2 shows the distribution of HA cases in Minnesota by annual average incidence of HA per 100,000 people by county for 2005 through 2010. Again, similar to Lyme disease reporting, incidence is attributed to county of residence, which may be different from the county in which HA was acquired. The highest rates are distributed in the north-central counties of the state, similar to Lyme disease, including Hubbard, Cass, Crow Wing and Aitkin counties, where tick habitat is abundant. The highest annual rate of HA was 189 cases per 100,000 in Cass County in 2010, followed by 149 cases per 100,000 in Crow Wing County in 2007. The highest total number of cases for a county was 69 in Hennepin County in 2010, followed by 68 cases in Crow Wing County in 2007. For both HA and Lyme disease, the number of cases varies annually and is affected by seasonal temperature and humidity (i.e., conditions that affect tick feeding and survival), as well as the number of visitors to the forested areas inhabited by ticks.

FIGURE VI-2: HUMAN ANAPLASMOSIS INCIDENCE 2005 - 2010

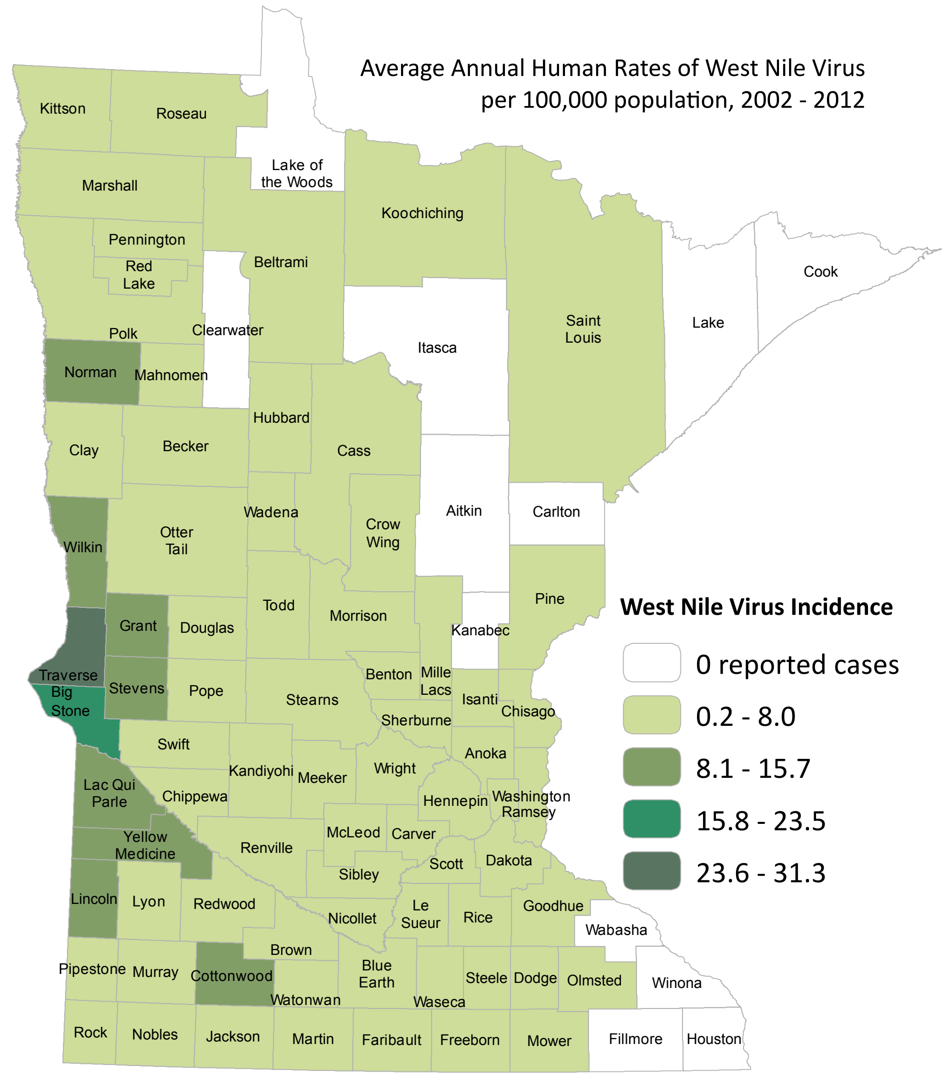


Data source: Minnesota Department of Health, Acute Disease Investigation and Control, 2011

WNV was first detected in Minnesota in 2002. The largest outbreak years were 2003 (148 cases), 2007 (101 cases) and 2012 (70 cases). The mosquitoes that carry the virus thrive in warm, dry conditions. They deposit eggs in standing water, such as drainage ditches or wetlands. Culex tarsalis (the primary vector mosquito species in Minnesota) is most prevalent in agricultural regions of western and central Minnesota, and rarely found in wooded areas. Risk for contracting WNV is highest from mid-July through mid-September, and typically peaks in August. Figure VI-3 shows the distribution of WNV cases in Minnesota by annual average rates of WNV per 100,000 people by county for 2002 through 2012.

The highest rates of WNV occur in western Minnesota where there is an abundance of farmland, and less in northeastern Minnesota where the land is still heavily forested. The highest annual rate of WNV was 146 cases per 100,000 in Big Stone County in 2007, followed by 128 cases per 100,000 in Traverse County in 2003. The highest total number of cases for a county was 11 in Hennepin County in 2003 and 2007. Testing for WNV has decreased since the early 2000s. The virus is not new anymore and people may be less likely to go to their doctor requesting a WNV test, especially people with the less severe West Nile Fever. As a result, cases may be underreported and it is suspected that incidences could be higher now, though it may not show in the data.

FIGURE VI-3: WEST NILE VIRUS INCIDENCE 2002 - 2012



Data source: Minnesota Department of Health, Acute Disease Investigation and Control, 2013

Populations Vulnerable to Vector-borne Disease

Populations at risk for Lyme disease or HA include those who live, work or travel in wooded areas known to have blacklegged ticks (especially north-central and southeastern Minnesota counties), particularly when exposed to brush and leaf litter from mid-May through mid-July (MDH, 2013f).

Although people of any age can get these tick-borne diseases, symptoms are often most severe in older adults or persons with impaired immune systems. See Figure IV-5 in Chapter IV for the percentage of population 65 years old and older by county in Minnesota. At the time MDH conducted this analysis, data were not available statewide for persons with impaired immune systems.

Populations at risk of WNV transmission include persons who live in or visit western and central Minnesota (especially agricultural regions) during warm, dry summers, as well as North Dakota or South Dakota, as these states have higher rates of WNV (MDH, 2013g). Persons vulnerable to symptoms of WNV include older adults (see Figure IV-5) and persons with compromised immune systems. Therefore, older adults living in western Minnesota are more vulnerable to severe symptoms of WNV, including encephalitis (inflammation of the brain).

Some studies indicate that persons of color may be disproportionately impacted by the spread of infectious diseases, including vector-borne diseases (CBCF, 2004; Hoetz, 2008). Some of the disproportionate effects may be more the result of lack of health insurance and regular medical access, as well as, socioeconomic status related to precautionary measures (Gage, 2008; CBCF, 2004). See Figure IV-9 in Chapter IV for the distribution of persons of color in Minnesota.

Effects of Climate Change on Vector Borne Diseases

Climate is one of many important interacting variables that affect people's risk for vector-borne diseases in Minnesota. Temperature and precipitation are key factors that determine abundance and distribution of vectors and the diseases that they carry. Climate change will affect the habitat that vectors thrive in, as well as, human behavior. According to MDH's Acute Disease Investigation and Control, "if the habitats ideal to vectors are ones where many people live or where people visit for recreational or job-related activities, incidence of vector-borne disease can be high" (MDH, 2013a).

Blacklegged ticks can carry Lyme disease or HA. Blacklegged ticks are most active on warm, humid days (MDH, 2013a). Climate change is expected to increase both temperatures and dew point, which could support ideal conditions for blacklegged tick activity. Climate change also will affect habitat for these ticks. Blacklegged ticks are most abundant in wooded or brushy habitats with abundant small mammals and deer (MDH, 2013a). Blacklegged ticks search for a host from the tips of low-lying vegetation and shrubs, not from trees (MDH, 2013h). They live in the brush or leaf litter, and therefore prefer deciduous trees that create abundant leaf litter through fallen leaves, rather than coniferous trees. As the climate warms, Minnesota's coniferous forests will likely move northward, followed by an expansion of deciduous forests, potentially increasing the preferred habitat for tick activity.

The mosquitoes that carry WNV thrive in warm, dry conditions. States like North and South Dakota that are warmer and drier than Minnesota have higher incidence of WNV (personal communication, David Neitzel, MDH, March 20, 2013). Minnesota is already warming. Longer growing seasons and earlier spring onset allows for greater virus amplification and more generations per year of mosquitoes, creating higher risk for WNV transmission. If seasons are too wet, other mosquito species may do better than Cx. tarsalis, but climate variability will likely result in heightened variability of precipitation and therefore drought potential. For example, 2012 was an ideal year for mosquitoes carrying WNV – including a long warm season, higher than normal temperatures, and drought across most of the state's farmland. According to MDH records, 2012 saw the third highest number of human cases (70) of WNV since 2002. It is possible that it was the actually the largest Minnesota WNV outbreak to date, because cases were likely underreported.

Also, new vectors and diseases have emerged, driven by milder winters and changing climate conditions. The Lone Star tick is a southern U.S. species that may be getting established in Minnesota (CDC, 2013a). Lone Star ticks do not carry Lyme disease, but can infect humans with the agents that cause southern tick-associated rash illness (STARI) and one form of human ehrlichiosis. MDH has documented low numbers of human ehrlichiosis cases in Minnesota in recent years (personal communication, David Neitzel, MDH, March 20, 2013). Symptoms include fever, headache, fatigue, and muscle aches (CDC, 2013b). With regard to mosquitoes, MDH has documented the presence of two exotic mosquito species (Asian tiger mosquito and Japanese Rockpool mosquito) new to Minnesota (personal communication, David Neitzel, MDH, July 12, 2013). Both will likely thrive in warmer, moister conditions and are potential disease carriers.

Image courtesy of Wikimedia Commons

VII Flooding and Flash Flooding

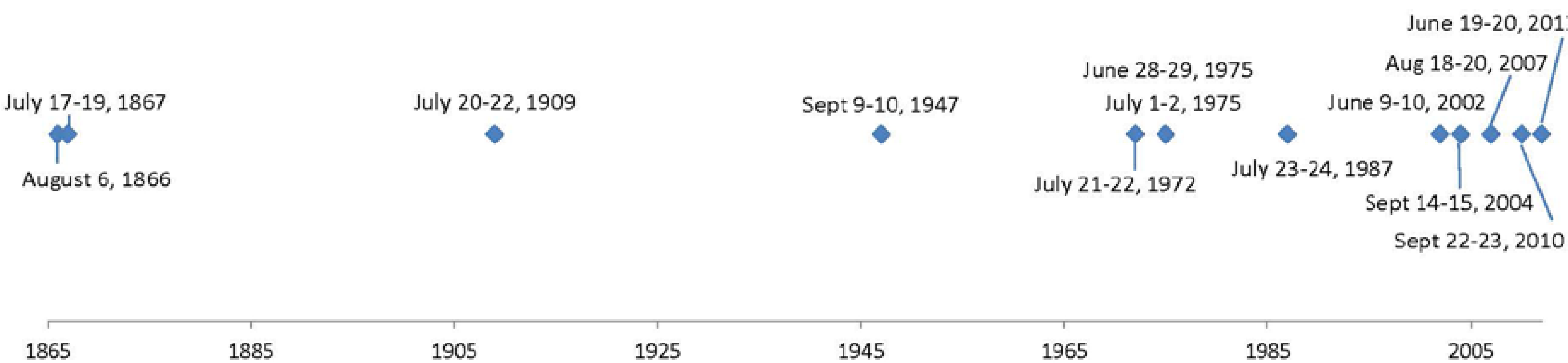
Background

Flooding occurs when normally dry land is submerged by 1) the overflow of rivers or other water bodies, or 2) the unusual and rapid accumulation or runoff of surface waters (FEMA, 2013a). While any location can flood, some areas are more susceptible to flooding. Regular spring flooding generally occurs in a floodplain, an area of low-lying ground adjacent to a river or susceptible to being inundated by water from any source. Flooding is affected by the amount of precipitation, the size and topography of the watershed, the regional and local climate, and land use characteristics. Flooding can be caused by prolonged periods of rainfall, intense short periods of rainfall, and/or melting of snowpack in the spring (HSEM, 2011).

Photo credits: Derek Montgomery for MPR (top), Rachel Agurkis (bottom)

2012 DULUTH/NORTHEASTERN MINNESOTA 500-YEAR FLOOD EVENT

FIGURE VII-1: HISTORIC MEGA-RAIN EVENTS 1866 - 2012



Source: Pete Boulay, DNR Climatologist, Minnesota Climatology Working Group

Flash floods are distinct from general flooding. As its name implies, a flash flood is a rapid event. Specifically, the flood must begin within six hours of the contributing event (e.g., intense rainfall, dam failure, ice jam) (NWS, 2009). In Minnesota, flash floods are defined as 24-hour rainfall events of six inches or greater (MCWG, 2012a). Ongoing flooding can become a flash flood if intense rainfall results in a rapid surge of rising flood waters (NWS, 2009). One main distinction between flooding and flash flooding is seasonality; flooding occurs during the spring, usually as a result of winter snow melt and spring rains, whereas flash flooding more often occurs during the summer or early fall as a result of heavy storm events.

Flash floods are expected to increase as a result of climate change driving more frequent heavy rain events. Figure VII-1 shows exceptional heavy rain episodes found by the Minnesota Climatology Office that reached six inches or more over a coverage of 1,000 square miles (MCWG, 2012b). These are precisely the kind of storms that cause flash flooding. There have been five of these exceptionally large events since 2002. While there is a historic precedent for these storms, at no time in recorded history have these events occurred as frequently as they do now.

Flash Flooding in Minnesota

The 2012 northeastern Minnesota flood occurred as a result of severe storms and record rainfall on June 19 and June 20. This 500-year storm event dropped up to 10.1 inches of rain on some areas of northeastern Minnesota in a 48-hour period. Damages to public infrastructure, including roads, bridges, and water and sewer systems (see images to the right), as well as, electric utilities and communications infrastructure, exceeded $108 million (Dayton, 2012). More than 1,700 private homes and over 100 businesses were impacted or damaged. The sustained high heat and humidity following the disaster exacerbated mold growth. Additional economic impacts included reduced tourism (resorts reported up to 50% cancellation rates following the disaster), temporary lay-offs and closures by local businesses (Dayton, 2012).

Many communities in Minnesota, representing counties, cities and Tribal nations participate in the Federal Emergency Management Agency (FEMA) National Flood Insurance Program (NFIP). The purpose of the NFIP is to mitigate future flood losses nationwide through community floodplain management ordinances and to provide access to affordable, federally backed flood insurance protection for property owners. Flood insurance premiums through the NFIP range from as low as $129 per year up to $3,289 per year depending on the building's risk level and the coverage value (FEMA, 2013b). However, if a home is destroyed by a flood that does not have flood insurance, the homeowner is responsible for all replacement and rebuilding costs.

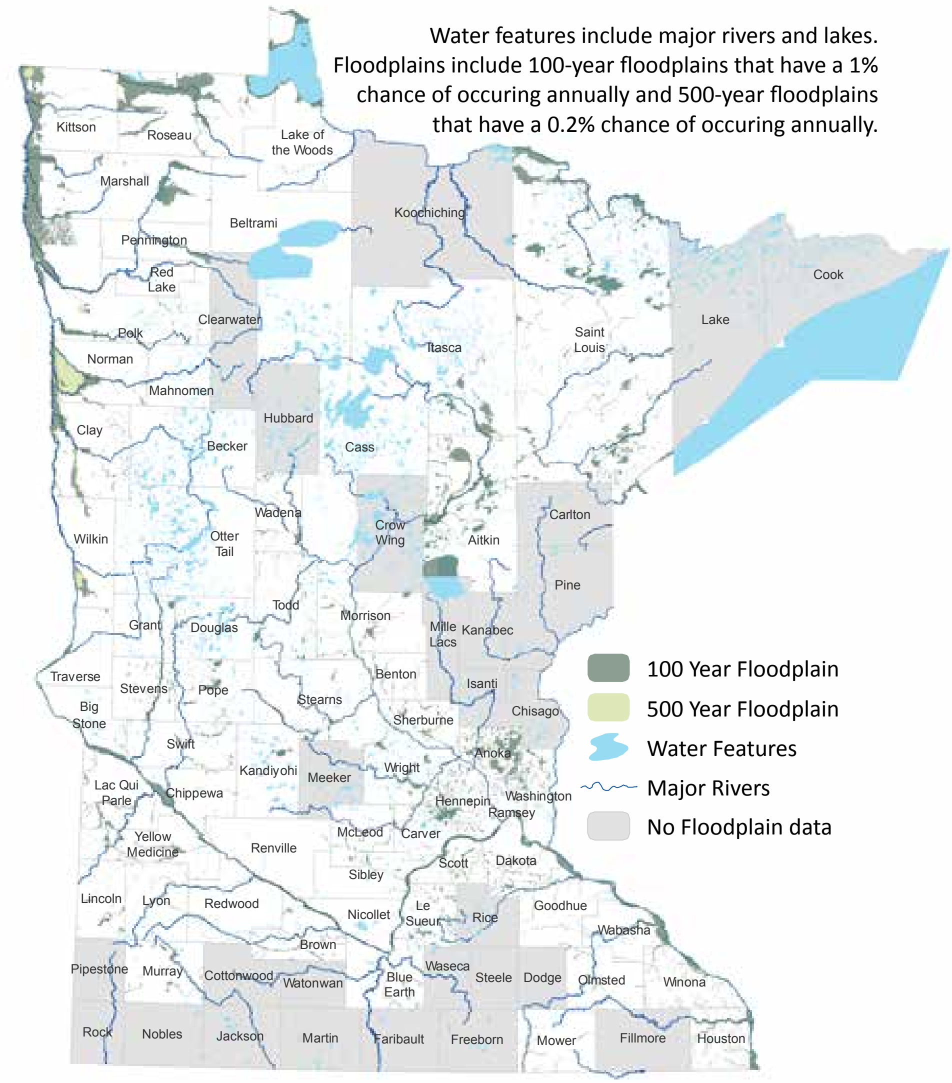
Photo credits: Derek Montgomery for MPR (top), Rachel Agurkis (bottom)

2012 DULUTH/NORTHEASTERN MINNESOTA
500-YEAR FLOOD EVENT

Part of NFIP participation includes mapping floodplains in the community to identify the risk of flooding and to create policies to mitigate risk. The FEMA Community Status Book indicates that 582 communities in Minnesota participate in the NFIP, while 86 communities do not participate but have an identified hazard area (FEMA, 2013c). Figure VII-2 depicts the 100- and 500-year floodplains from FEMA overlaid with major rivers and lakes. Floods have a 1% chance per year of happening in a 100-year floodplain and a 0.2% chance per year of happening in a 500-year floodplain.

Figure VII-2 shows that there are still several Minnesota counties that either have no floodplains mapped or have incomplete maps. Counties that do not have FEMA digitized floodplain data available are indicated with grey color coding; some of the counties have only partial floodplain information. According to a 2013 U.S. Government Accountability Office report, FEMA has not placed a high priority on mapping rural areas, including many tribal lands, for flood risk. As a result, a good portion of lands remain unmapped (US GAO, 2013). Without flood hazard maps, communities may be unaware of their flood risk, even in high-risk areas. Partly for this reason, communities may perceive their risk of flooding as relatively low. Alternately, in the absence of NFIP participation, communities may have a land use plan that includes some kind of suitability analysis with land use controls related to flooding. This information is not available in a public dataset and is not included in this assessment.

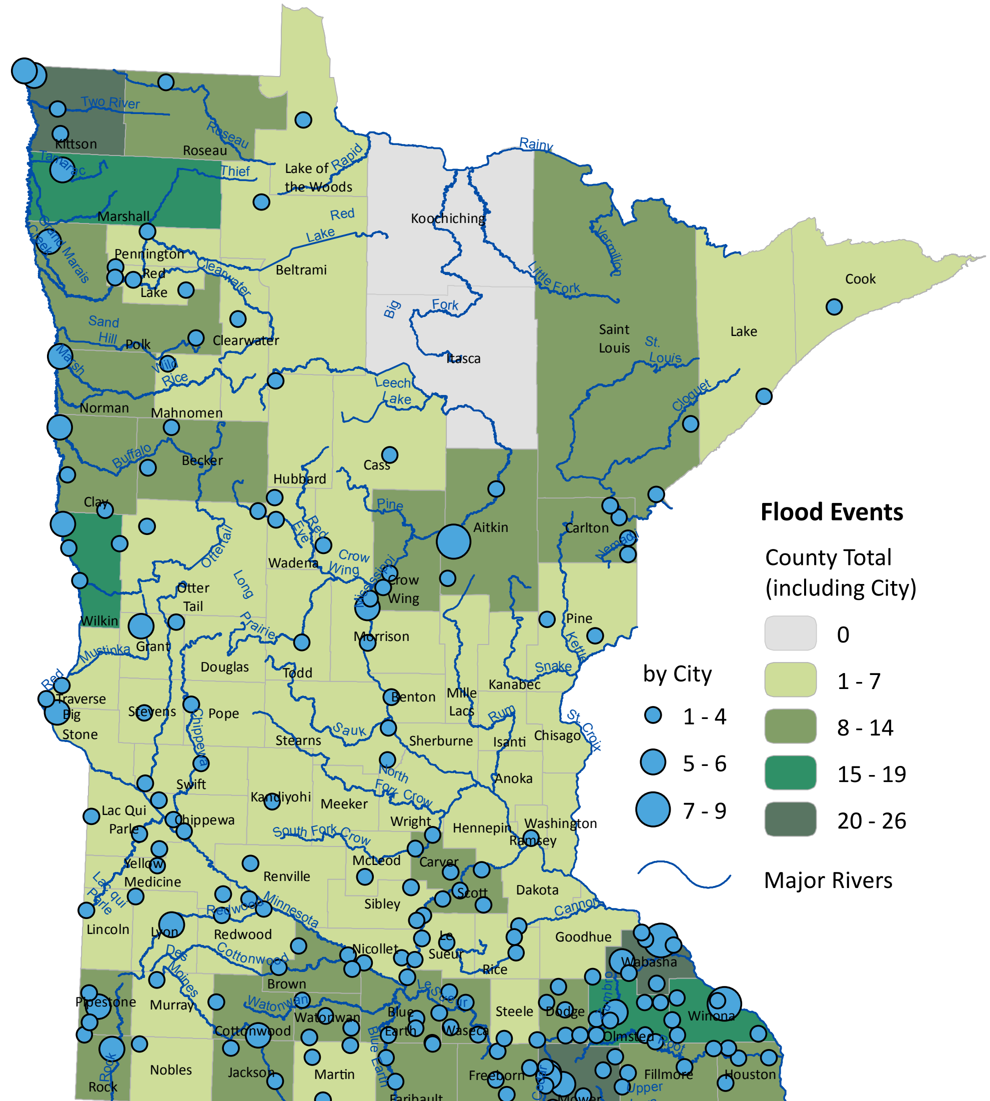
FIGURE VII-2: WATER FEATURES AND FLOODPLAINS



Data sources: FEMA Floodplain, 2013 and Minnesota DNR Hydrography, 1999

Floodplains around the major rivers and lakes are the areas that are most likely to flood during regular spring flooding. Figure VII-3 shows where flood events (excluding flash floods) have occurred in Minnesota between January 1, 2000 and December 31, 2012. Depicted flood events include those that are categorized by the National Oceanic and Atmospheric Administration's (NOAA) Storm Events Database as any high flow, overflow, or inundation by water that causes or threatens damage. River flooding may be included, but flash floods are not. The highest concentrations of floods by county are located in northwest and southeast Minnesota. In general, these floods correspond with major rivers and floodplains depicted in Figure VII-2. However, the number of events alone does not determine a community's risk. Some communities that flood frequently, such as Rochester, MN, have taken mitigation precautions and have lowered their risk of damage from flood waters.

FIGURE VII-3: FLOOD EVENTS BY CITY AND COUNTY FROM JANUARY 1, 2000 TO DECEMBER 31, 2012



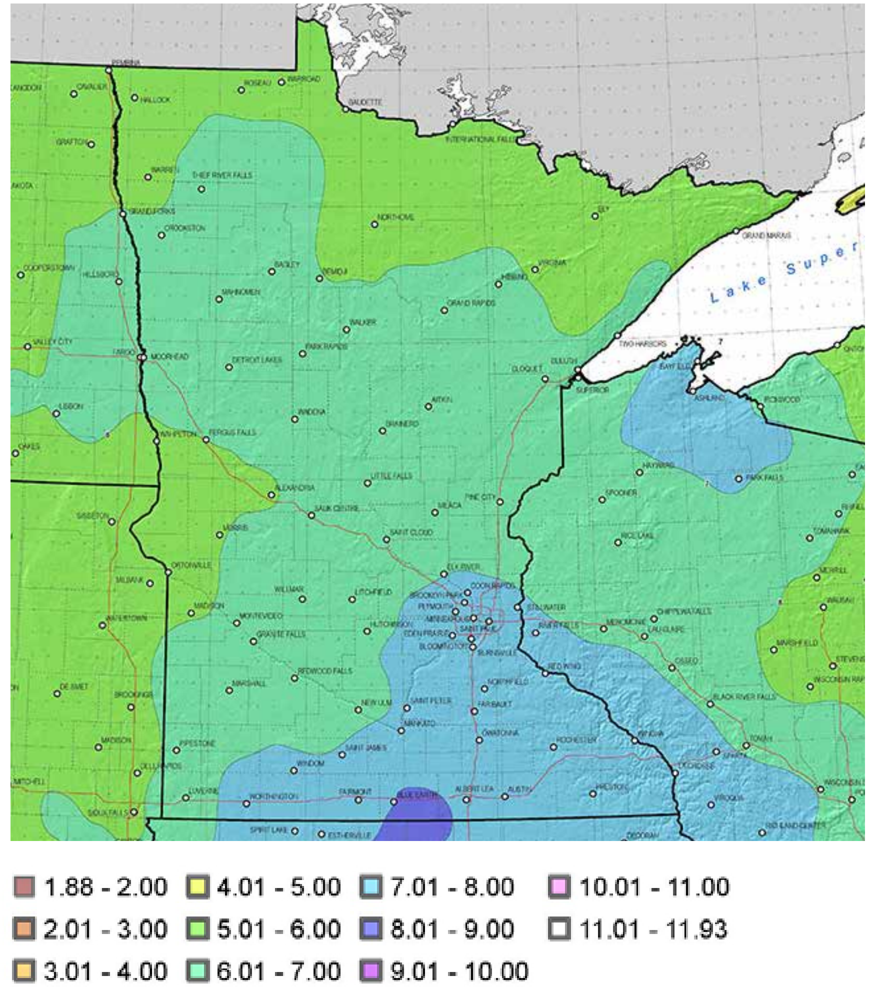
Data source: NOAA Storm Events Database, 2013

Rapid rainfall events, including those with the probability of occurring once in every 100 years or more, are one of the primary causes of flooding and particularly flash floods. Figure VII-4 shows the rainfall amounts for rain events 24 hours in length with the probability of occurring once every 100 years. In northern and western Minnesota, 100-year 24-hour rain events are estimated to drop five to six inches; whereas in southern Minnesota estimated rainfall goes up to eight to nine inches in 24 hours. These amounts are important for land use planning and emergency management operations.

The rainfall estimates depicted in Figure VII-4 were released in spring 2013 by the NOAA Atlas 14 project (NOAA, 2013a). Prior to this recent release, planners and engineers were using rainfall frequency estimates from a technical paper published in 1961.

Flooding and flash flooding is enhanced by the amount of impervious surface in an area, or the combined amount of roads, rooftops and other impervious surfaces. Figure IV-4 in Chapter IV displays the percent of land cover across Minnesota that is considered impervious. The high percentages of impervious surface in the Twin Cities metro area stands out most notably, as well as St. Cloud, Rochester, Duluth and other cities in the state. Smaller cities also are vulnerable to flooding from impervious surfaces given that any amount of impervious surface that limits water from infiltrating can increase the risk for flooding and flash flooding. According to the Minnesota Division of Homeland Security and Emergency Management (HSEM), "urban areas are increasingly subject to flash flooding due to the removal of vegetation, covering of ground cover with impervious surfaces, and construction of drainage systems" that channel water quickly to one area and reduce infiltration (HSEM, 2011).

FIGURE VII-4: MINNESOTA 100-YEAR 24-HOUR PRECIPITATION FREQUENCY ESTIMATES (IN INCHES)



Source: NOAA Atlas 14, Volume 8, Version 2, Midwestern States

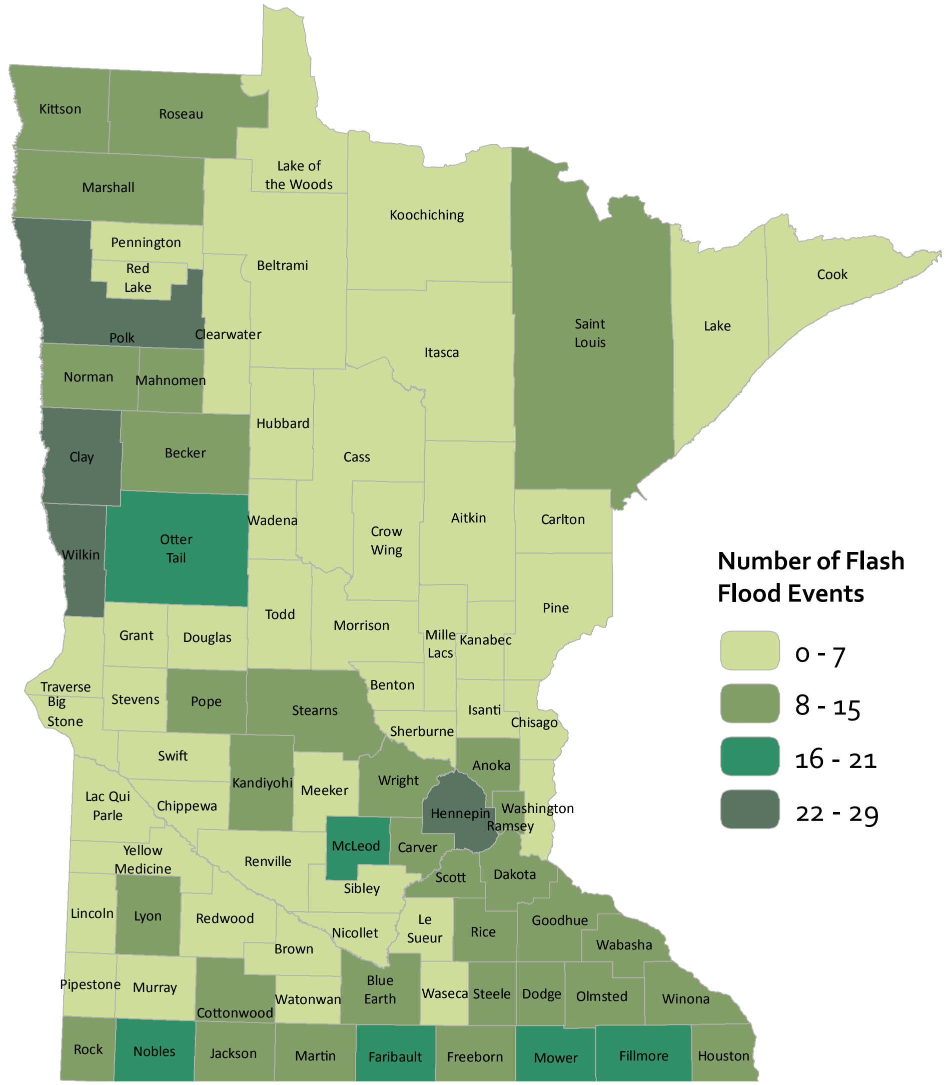
Figure VII-5 shows the number of flash floods by county in the last 18 years. Multiple events on the same day within the same county were counted as one event. Flash floods are defined by NOAA as:

A rapid and extreme flow of high water into a normally dry area, or a rapid water level rise in a stream or creek above a predetermined flood level, beginning within six hours of the causative event (e.g., intense rainfall, dam failure, ice jam-related), on a widespread or localized basis.

Ongoing flooding can intensify to flash flooding in cases where intense rainfall results in a rapid surge of rising flood waters. Flash floods also may include river flooding that develops as a result of flash flooding.

The areas with the greatest number of flash floods include northwestern counties of Polk, Clay and Wilkin; Hennepin county, and counties along the southern border and southeastern Minnesota.

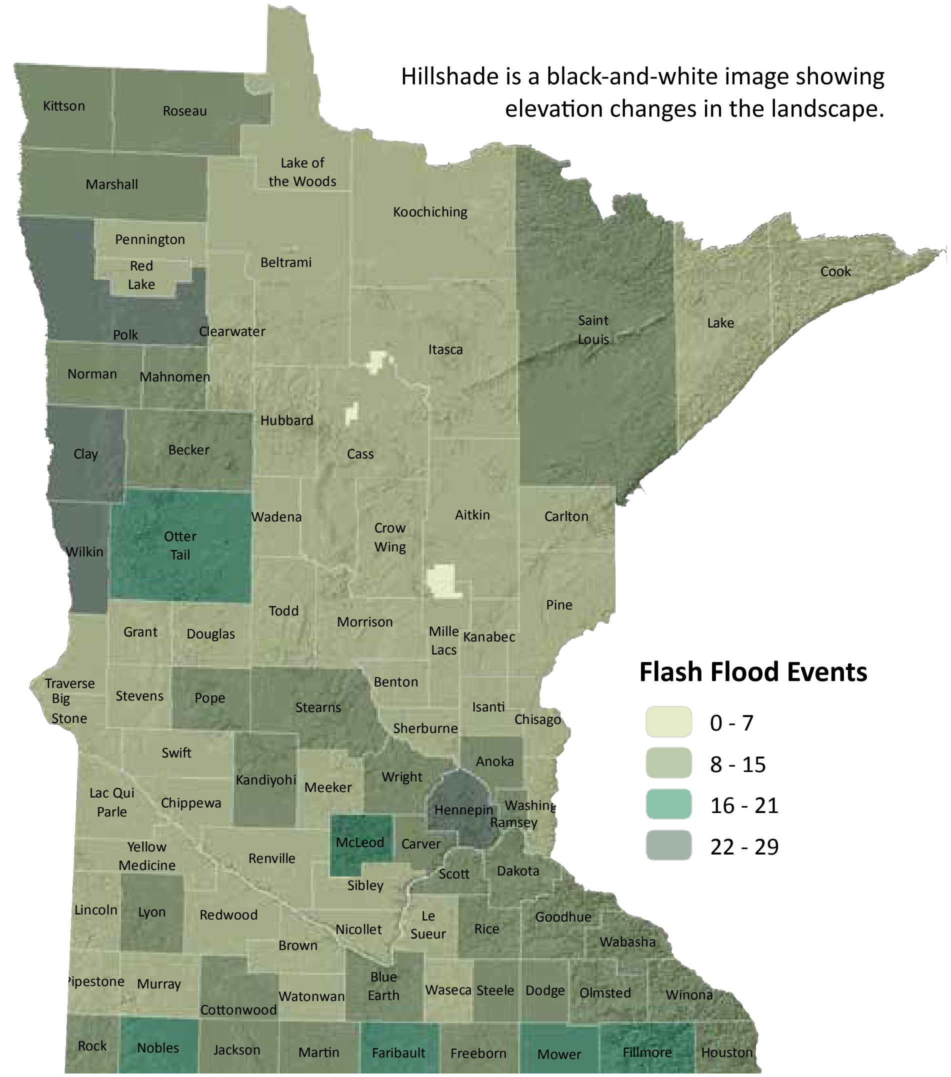
FIGURE VII-5: NUMBER OF FLASH FLOODS BY COUNTY 1996 - 2013



Data source: NOAA Storm Events Database, 2014

Figure VII-6 builds upon Figure VII-5 by layering it with hillshade. Hillshade is represented as a black-and-white image showing elevation changes in the landscape. It is created from a digital elevation model as if the elevation surface were illuminated by a hypothetical light source shining from the northwest (MnGEO, 2013). Elevation in northeast and southeast Minnesota is more varied than the rest of the state. Steep slopes can promote flash floods.

FIGURE VII-6: HILLSHADE AND FLASH FLOOD EVENTS BY COUNTY 1996-2012



Data sources: NOAA Storm Events Database, 2014 and MnGeo WMS service – Hillshade (LIDAR), 2013

Populations Vulnerable to Flooding

Specific populations are more vulnerable during floods, including older adults, particularly if they are living alone; persons who possess a physical or mental illness that impairs the individual's ability to provide adequately for his or her own care without assistance; persons with limited economic resources; persons of color; persons living in substandard housing or mobile homes; persons without a vehicle; and persons who are not proficient in English. People with respiratory illness may be more vulnerable to mold development following flooding. People who rely on private wells may be more vulnerable to drinking-water contamination as a result of flooding.

Older adults and persons with physical, mental or emotional conditions are vulnerable to flooding primarily because they may need assistance to evacuate or care for themselves before, during or after a flood event (English et al., 2009; Keim, 2007; O'Neill, 2009). Older adults also are less likely to leave their homes following evacuation orders even if they are in good health or have sufficient resources (Cutter et al., 2003). Older adults who are socially isolated or live alone are particularly vulnerable because they may not have friends, family or neighbors to check on them or ensure that they evacuate.

Image courtesy of Wikimedia Commons

Figure IV-6 in Chapter IV shows the percentage of households by county with persons 65 years old and over living alone. The counties with the highest percent of households having older adults living alone include Traverse (20%), Big Stone (19.2%), Lincoln (18.3%), Chippewa (17.6%), Swift (17.5%), Norman (17.3%), and Wadena (16.4%). Many of these western Minnesota counties contain 100- and 500-year floodplains, including Norman between the March and Wild Rice Rivers, and Big Stone and Chippewa along the Minnesota River. However, flood and flash flood events are not as common here as in southeastern and northeastern Minnesota

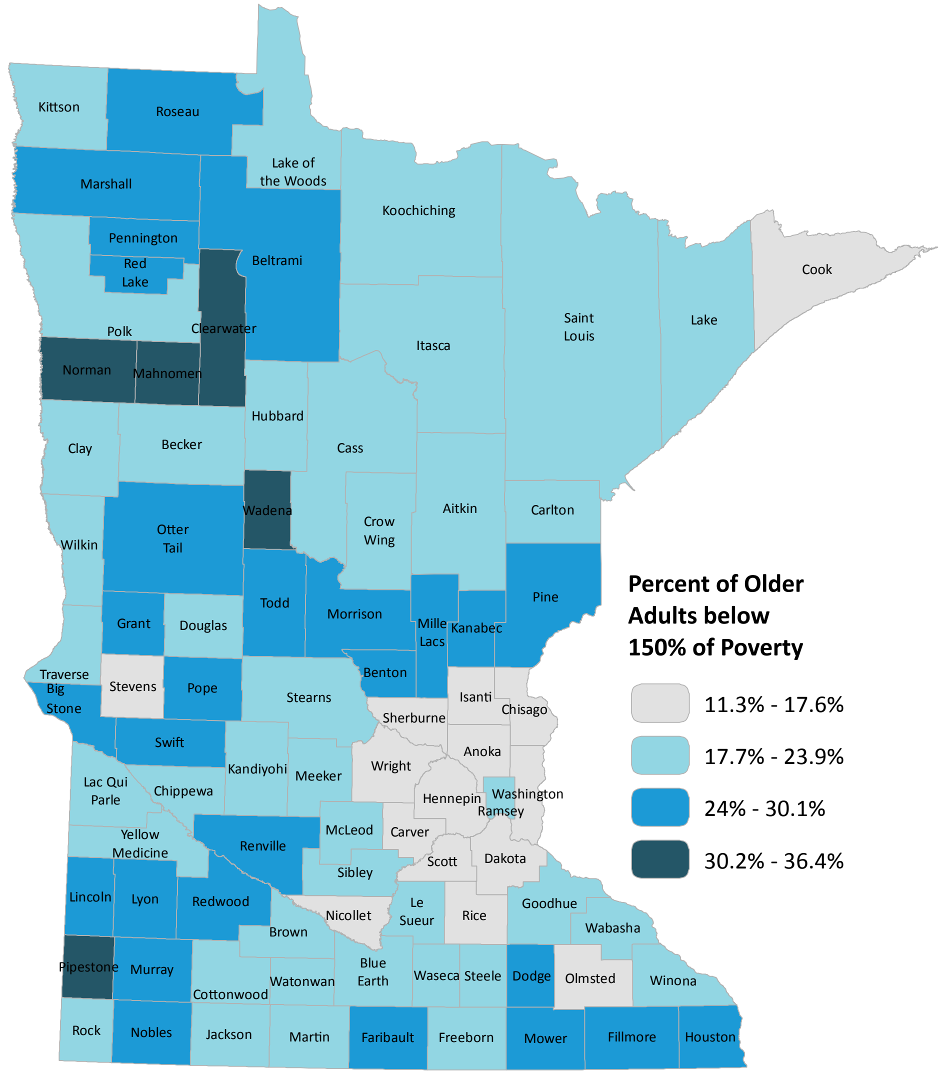
At the time the CCVA was conducted, county-level data for persons with disabilities are only available for 49 of the 87 Minnesota counties. These data are collected by the American Community Survey conducted by the U.S. Census Bureau (US Census Bureau, 2012). Given the extensive data gaps across the state the CCVA does not include these data. Also, licensed-care residences for older adults and persons with physical or mental disabilities were not mapped for this project. These residences generally have emergency relocation plans; as a result, residents may be less vulnerable than persons living on their own or outside of licensed care housing.

Populations with lower incomes and fewer economic resources may be more vulnerable to floods due to the cost of evacuation, relocation and/or rebuilding after the flood (Keim, 2006; Morrow, 1999). Persons with income levels at or below poverty may already face difficulties in obtaining their basic needs. Older adults that receive social security income often make just over the poverty threshold.

Figure VII-7 shows the percent of the population 65 years and older with income below 150% of poverty. This income threshold is used to account for older adults receiving social security that would not be captured with the poverty threshold. The income level for 150% of poverty for the 2011 American Community Survey was $16,182 for a single person 65 years and over, or $20,413 for a couple (US Census Bureau, 2011).

Four counties in northwest Minnesota, Clearwater, Mahnomen, Norman and Wadena, as well as one county in southwestern Minnesota, Pipestone, had approximately one-third of their older adults living at or below 150% of poverty. A large portion of Norman is in a floodplain, potentially increasing flooding threats for an already vulnerable population. Older adults with incomes below 150% of poverty in southeastern Minnesota, like Mower County, may be more at risk because flash floods occur more in that area than other parts of the state.

FIGURE VII-7: PERCENT OF OLDER ADULTS LIVING BELOW 150% OF POVERTY



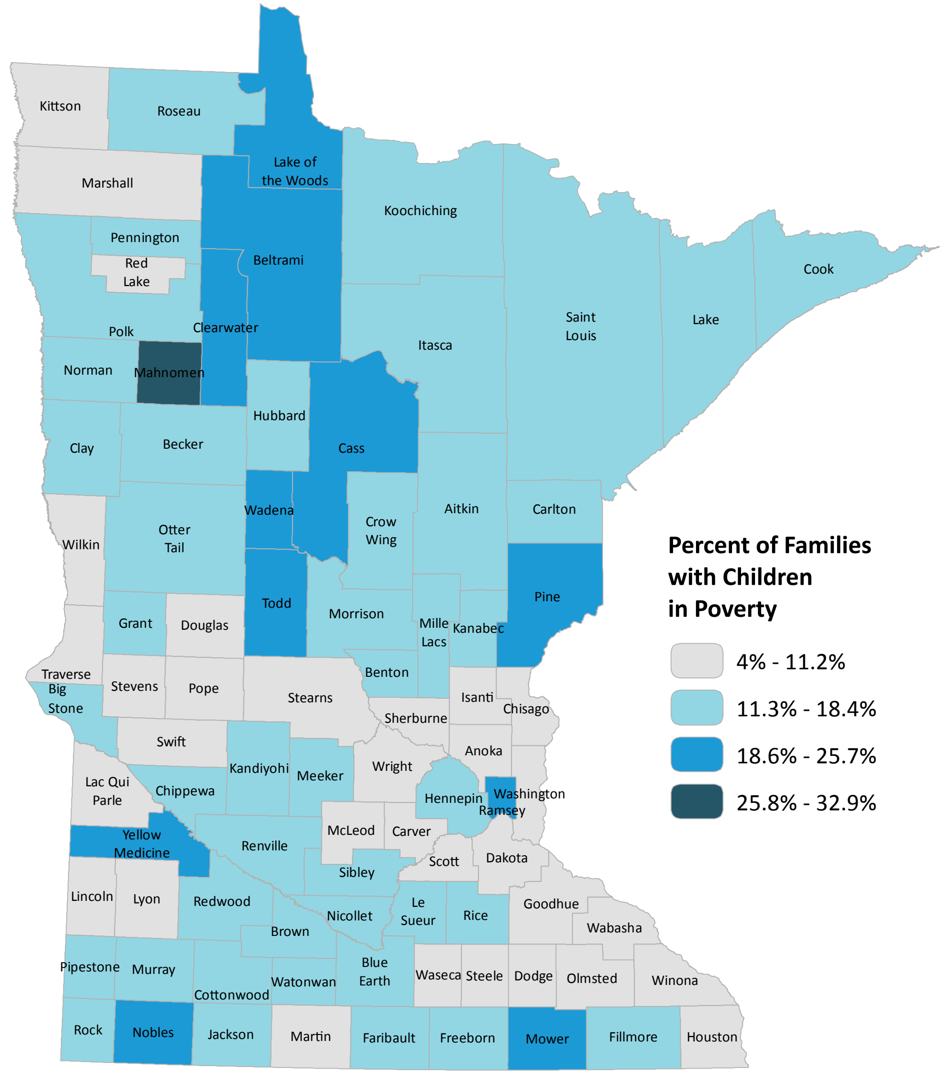
Data source: American Community Survey 5-Year Estimates 2007-2011

There are a number of limitations related to using 150% of poverty as the income-burden threshold for older adults. For example, basic living expenses vary based on household type and size, geographic location, health status and a person's need for day-to-day support (long-term care). Therefore, 150% of poverty, or just under $23,000, may be more than or less than the amount needed by an older person to meet their daily living expenses. These limitations also apply more generally. Poverty is determined by a national threshold level, whereas cost of living varies by region. Cost of living is often greater in urban areas and lower in rural communities, though community services may not be as readily available in communities outside urban settings.

At the other end of the age spectrum, children also are vulnerable to disasters such as flooding events. Families, especially single-parents with children and incomes at or below the poverty line have a more difficult time preparing for or recovering from floods (Keim, 2006; Morrow, 1999).

Figure VII-8 shows that north-central Minnesota has a number of counties with over 20% of families with children living in poverty. Mahnomen County is the highest in the state with 32.9%, followed by Beltrami (22.3%), Wadena (22.2%), Clearwater (21.6%), and Lake of Woods (20.5%). Nobles County in southwestern Minnesota had 22.2% of families with children living in poverty, and Pine County in eastern Minnesota had 20.2%. The income threshold for poverty for a family of four (two parents and two children) in 2011 was $22,811, or $22,891 for one parent and three children (US Census Bureau, 2011).

FIGURE VII-8: PERCENT OF FAMILIES WITH CHILDREN IN POVERTY BY COUNTY



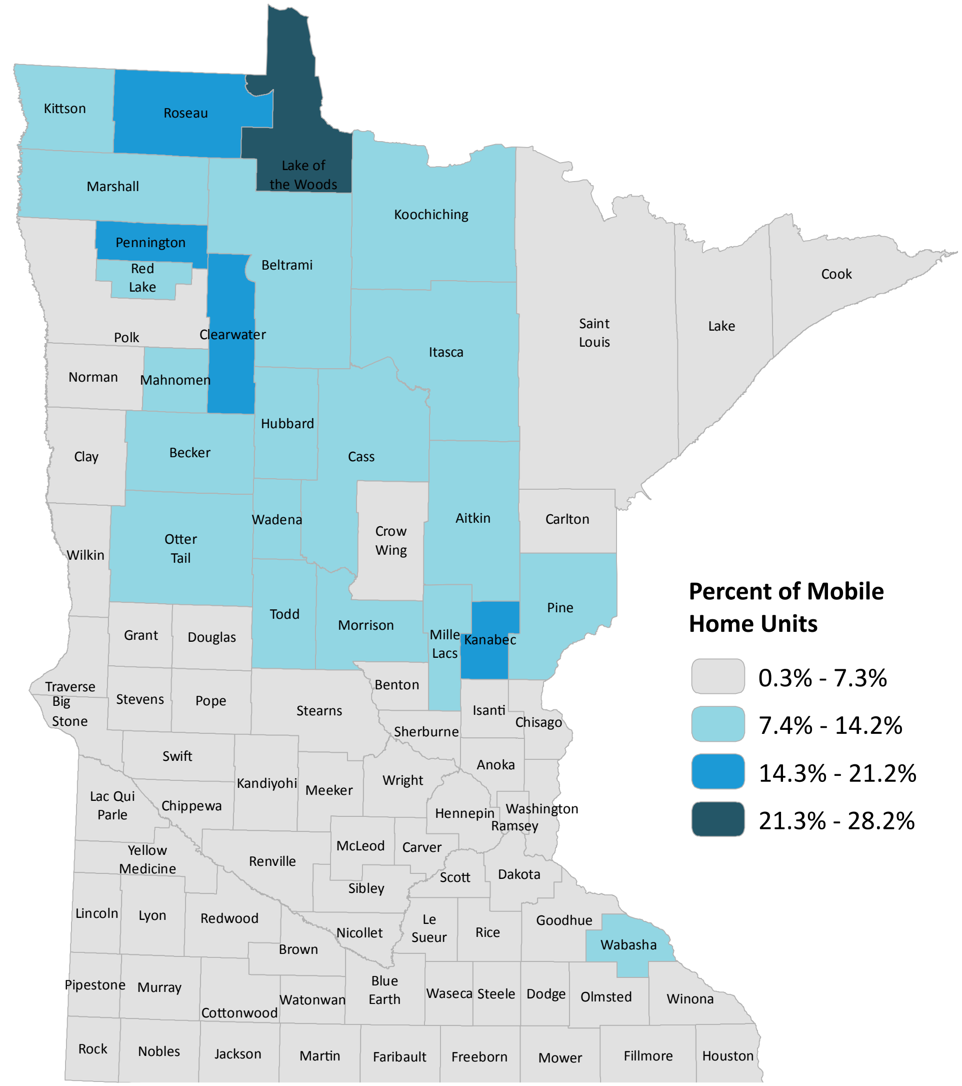
Data source: American Community Survey 5-Year Estimates 2007-2011

Similar to extreme heat events, race and/or ethnicity may increase vulnerability to impacts from flood and flash-flood events (Lin, 2008). Existing health disparities and other inequities increase vulnerability (Luber et al., 2014). "For example, Hurricane Katrina demonstrated how vulnerable certain groups of people were to extreme weather events, because many low-income and of-color New Orleans residents were killed, injured, or had difficulty evacuating and recovering from the storm" (Luber et al., 2014). Additionally, the higher rates of respiratory disease prevalence and mortality among persons of color may increase their vulnerability to the indirect effects of floods, such as mold and allergen development. See Figure IV-9 in Chapter IV for the distribution of persons of color in Minnesota.

The physical condition of a person's home may increase their vulnerability to flooding. Flooding is more likely to damage homes that are poorly built, built in a floodplain, and/or are mobile or modular style homes (Morrow, 1999; Cutter et al., 2003).

Figure VII-9 shows that the highest percentage of mobile home units of total housing stock is in Lake of the Woods County (28.2%), and percentages overall are higher in northern Minnesota than elsewhere in the state. Fortunately, there have been fewer reported floods in these counties, except in the northwestern counties of Kittson, Roseau and Marshall.

FIGURE VII-9: PERCENT OF ALL HOUSING UNITS THAT ARE MOBILE HOMES BY COUNTY

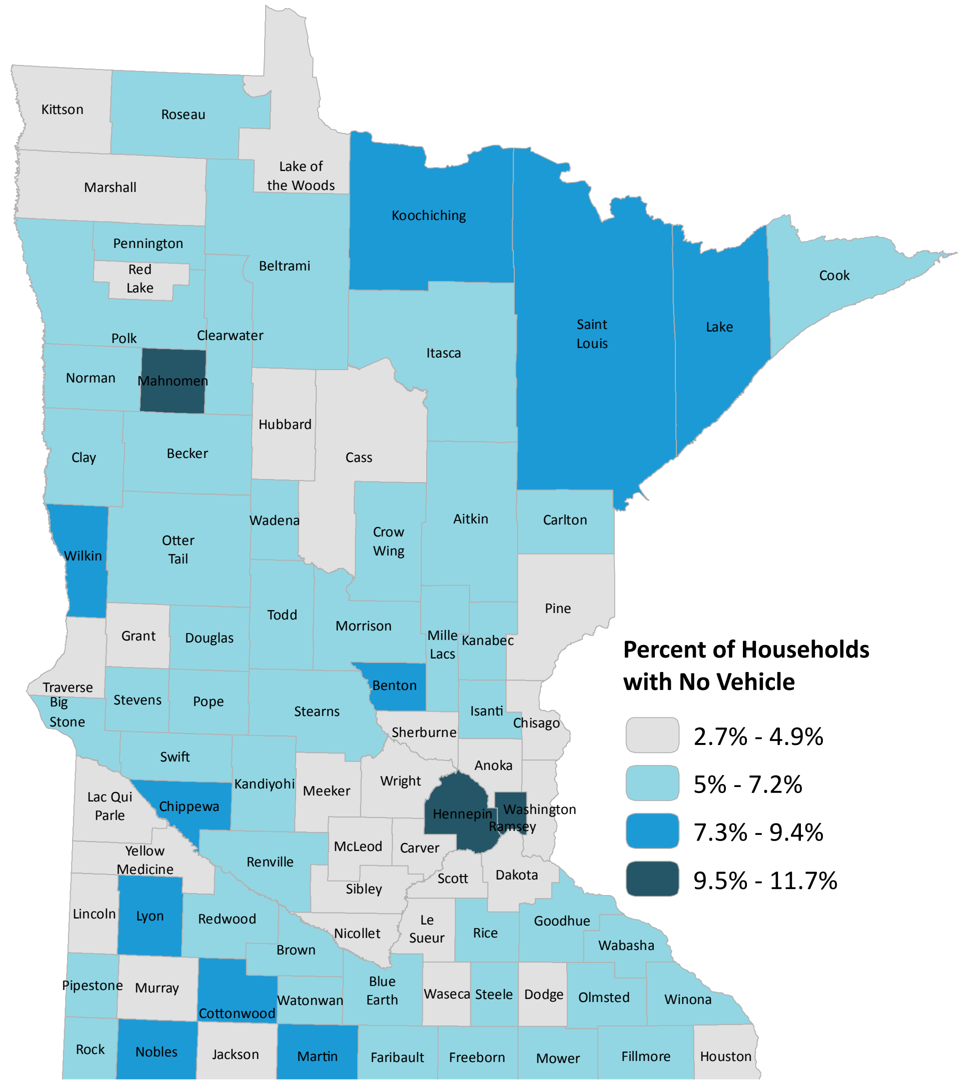


Data source: American Community Survey 5-Year Estimates 2007-2011

Access to a personal vehicle is a critical factor for mobility during a flood event. Households without such access are more vulnerable due to their dependence on public transportation or others to evacuate in an emergency (Morrow, 1999; Cutter et al., 2003).

Figure VII-10 shows that the highest percentages of households with no access to a personal vehicle are located in Mahnomen (11.7%), Ramsey (11.3%) and Hennepin (10.5%) counties. In Ramsey and Hennepin counties, public transit is more readily available. However, in Mahnomen, and some of the northeastern and southwestern counties that have more than 7% of households with no access to a vehicle, public transit may not be an option to evacuate.

FIGURE VII-10: PERCENT OF HOUSEHOLDS WITH NO VEHICLE



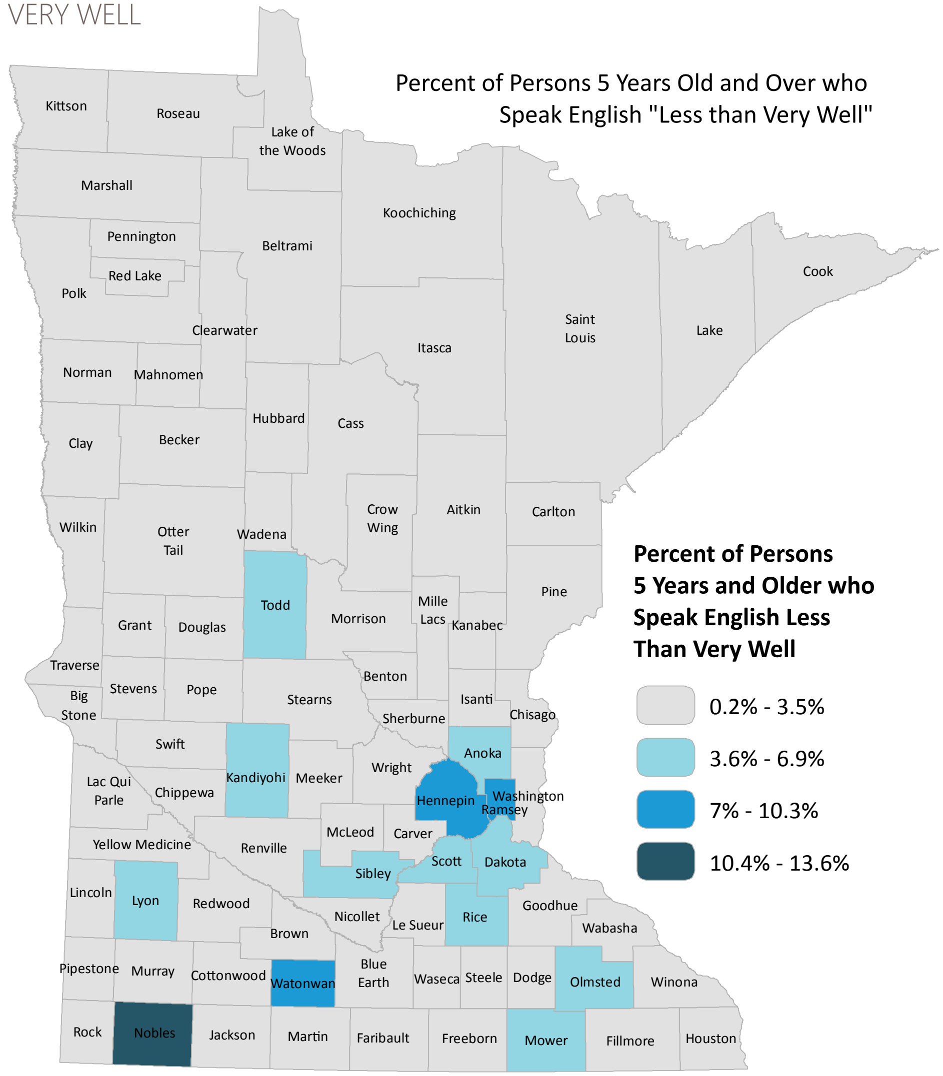
Data source: American Community Survey 5-Year Estimates 2007-2011

Additional complications during preparation for or recovery from flood events can occur if there are language barriers. Emergency response or evacuation information, as well as, forms to receive aid following a disaster may be provided in languages other than English, but this is not always the case. Populations that speak a language other than English and have limited English proficiency can be at a higher risk for adverse health outcomes during floods as a result of communication barriers (Morrow, 1999; Cutter et al., 2003).

Figure VII-11 shows the percent of persons five years and older by county who speak English "less than very well." Limited English proficiency represents a person's perception about his or her own ability to speak and understand the language. In the American Community Survey the U.S. Census Bureau asks whether the person completing the survey speaks a language other than English, what that other language is, and whether the person speaks English 'very well,' 'well,' 'not well,' or 'not at all.'

The information summarized in Figure VII-11 shows the responses to the question for those who selected 'well,' 'not well,' or 'not at all.' The percent of population that speaks English 'less than very well' is higher in southern Minnesota counties. The highest percentages of limited English proficiency occur in Nobles, Watonwan, Hennepin and Ramsey Counties. Flooding and flash flood events are not as frequent here as in others southern Minnesota counties, but floods do occur that could threaten limited English speaking persons.

FIGURE VII-11: LIMITED ENGLISH PROFICIENCY - PERCENT OF PERSONS 5 YEARS AND OLDER WHO SPEAK ENGLISH LESS THAN VERY WELL



Data source: American Community Survey 5-Year Estimates 2007-2011

TABLE VII-1: COMPOSITE FLOOD VULNERABILITY SCORES BY VARIABLE

Variable	1 (Low Vulnerability)	2 (Mild Vulnerability)	3(Moderate Vulnerability)	4 (High Vulnerability)
Proportion of households with no vehicle by county	2.7 – 4.5%	4.6 – 5.6%	5.7 – 6.6%	6.7 – 11.7%
Proportion of housing units that are mobile homes by county	0.3 – 3.1%	3.2 – 4.8%	4.9 – 8.8%	8.9 – 28.2%
Proportion of households that are adults 65 years old and older living alone by county	5.5 – 9.9%	10.0 – 11.9%	12.0 – 14.0%	14.1 – 20.0%
Proportion of families with children that are living at or below poverty by county	4 – 9.6%	9.7 – 12.7%	12.8 – 15.4%	15.5 – 32.9%
Proportion of persons of color	2.2 – 4.7%	4.8 – 7.1%	7.2 – 10.9%	11.0 – 48.6%
Proportion of persons 5 years old and older who speak English less than 'very well' by county	0.2 – 0.7%	0.8 – 1.4%	1.5 – 2.3%	2.4 – 13.6%
Flash floods by county 1996 – 2013	0 – 7 flash floods	8 - 15 flash floods	16 - 22 flash floods	23 - 29 flash floods

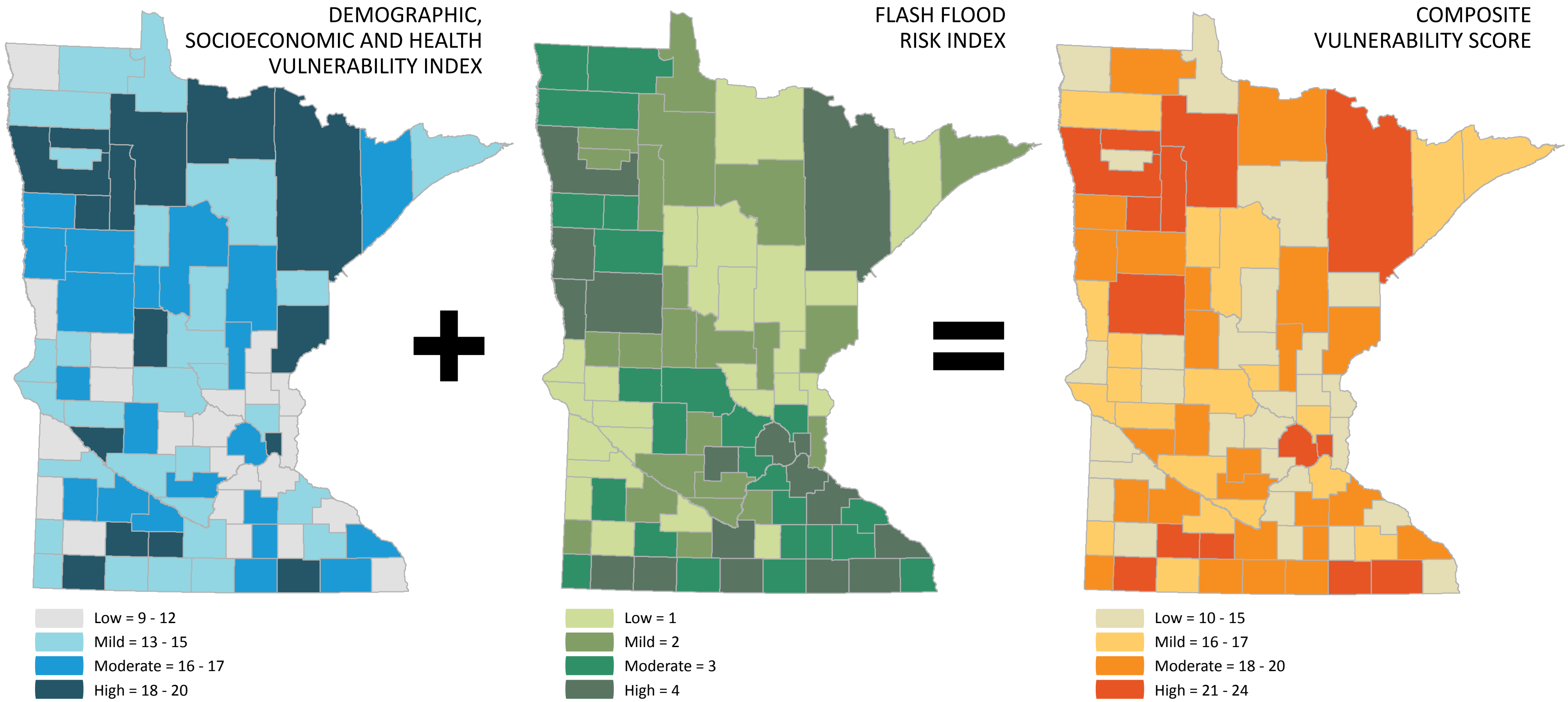
Composite Flood Vulnerability

In an effort to understand the impact of population vulnerability associated with flooding, MDH created a set of composite vulnerability maps for floods that combine population vulnerability and risk to flash floods. In Figure VII-12, the image on the far left combines the following variables for population vulnerability: 1) households with no vehicle, 2) mobile housing units, 3) older adults living alone, 4) families with children living in poverty, 5) persons of color, and 6) limited English proficiency. The center image demonstrates risk for flooding by showing the past number of flash flood events. Impervious surface and slope, while having an impact on risk for flash floods and mapped previously in this report, were not included in the composite map. The image on the right is the combination of the population vulnerability and flash flood risk.

The values of each variable were ranked into quartiles and scored 1 for the first quartile to indicate the lowest vulnerability to 4 for the fourth quartile to indicate the highest vulnerability. Table VII-1 shows the scores and range of values for each variable. The scores for each county were summed across variables to come up with the composite score. The composite scores for all counties are displayed by quartile in Figure VII-12. No weights were applied to the variables.

Figure VII-12 identifies a number of counties that are more vulnerable to flash floods as a result of the composite score that would not otherwise rank as high due to incidence of flash floods alone. Mower County in southeast and St. Louis County in the northeast are highly vulnerable for both population vulnerability and flash flood risk. However, other counties that did not have high flash flood risk, such as Pennington and Chippewa, have high vulnerability to flash floods in the composite map due to the inclusion of other variables of vulnerability. This is information provides emergency managers and planners evidence of their communities' historical risk for flooding, as well as, the vulnerability of their communities to flash flooding.

FIGURE VII-12: POPULATION VULNERABILITY, FLASH FLOOD RISK, AND COMPOSITE FLOOD VULNERABILITY MAPS



Effects of Climate Change on Flash Floods

In Minnesota, climate change will impact flooding principally through changes in precipitation. Precipitation is projected to increase in winter and spring, and to become more intense throughout the year (Karl et al., 2009). This pattern is expected to lead to more frequent flooding, increasing infrastructure damage, and impacts on human health.

Already in Minnesota, heavy rainfall events have increased (Karl et al., 2009). Overall amounts of precipitation may increase slightly, but the primary change will be the increase in the amount of precipitation that falls during heavy precipitation events rather than smaller, more frequent rainfalls. Heavy rainfall events and increased intensity of rainfall will increase soil erosion and runoff. Also, soil condition is a factor in runoff and erosion. The increased intensity of rainfall events may be accompanied by less frequent rain and drier soils between rainfall events. Warmer winters could reduce snow cover that may increase the depth of soil freezing during cold snaps because snow cover insulates the ground from freezing. Dry soils or frozen soils can reduce infiltration and increase runoff and possibly erosion (Sinha & Cherkauer, 2010). Runoff effects are further amplified by changes in land use. For example, development that increases impervious surfaces, combined with the increased heavy rainfall events, will increase the potential for flooding, property damage, and human health impacts (Karl et al., 2009).

Overall, increases in heavy rainfall events are likely to cause greater property damage, higher insurance rates, a heavier burden on emergency management, increased clean-up and rebuilding costs, and a growing financial toll on businesses, homeowners, and insurers (Karl et al., 2009).

VIII Drought

Background

There are many ways to measure and define drought, and no one universally accepted definition exists (HSEM, 2011). In general, drought implies less than expected amounts of precipitation over an extended period of time (WRRC, 1987; HSEM, 2011).

According to NOAA, there are four types of drought: 1) meteorological drought, defined by less than normal precipitation over time; 2) hydrological drought, which addresses the effects of meteorological drought on streams, reservoirs and groundwater level; 3) agricultural drought, defined by soil moisture deficiencies that can affect crop production; and 4) socioeconomic drought, which addresses the supply and demand of various commodities during drought (HSEM, 2011; NCDC, 2013b). Climatologists in Minnesota are primarily concerned with hydrologic drought, which can have profound negative impacts on water-dependent industries, including agriculture, public utilities, forestry and tourism (DNR, 1989).

While there are several measures of drought, the one most commonly used in the U.S. is the Palmer Drought Severity Index (PDSI) (NOAA, 2013b). The PDSI is a measure of long-term meteorological drought. PDSI calculates the difference between expected and observed precipitation for each climactic division (WRRC, 1987). When precipitation is below the expected amount, PDSI is negative (-); when precipitation is above normal, PDSI is positive (+).

Image courtesy of Wikimedia Commons

Drought is measured with four levels of intensity (WRRC, 1987):

- Mild (PDSI -1 to -2): Some of the native vegetation almost ceases to grow.
- Moderate (PDSI -2 to -3): The least tolerant species of the native plant community begin to die and be replaced by more drought-resistant species.
- Severe (PDSI -3 to -4): Only the most drought-resistant species of native vegetation continue to grow. Vegetal cover decreases.
- Extreme (PDSI -4 and lower): Drought resistant species gradually give way to bare soil.

Drought conditions build slowly. The PDSI is a reflection of past low precipitation amounts, since there is a lag in reduced precipitation and accumulation of drought conditions. Similarly, as precipitation returns to normal, there is a lag in the PDSI returning to zero or above.

Drought is a concern because of its cascading effects on our environment and eventually on our health. Unlike other natural hazards, the impact of drought is less obvious and may be spread over a larger geographic area. Extended periods of drought, especially when combined with heat, may affect agricultural crops, livestock, dairy production, water quantity and quality, and the risk of wildfire. Wildfires can cause injury, loss of property and particulate air pollution. The 2011 Boundary Waters Canoe Area wildfire burned nearly 145 square miles and cost $21 million. Smoke and ash spread as far as northeast Wisconsin and Traverse City, Michigan (MPR, 2011). Similarly, smoke from fires in Colorado and other western states can affect the Air Quality Index here in Minnesota (Huttner, 2012).

Drought also can impact air quality by increasing the amount of airborne dust particles. During the drought of the 1930s, dust storms were a regular occurrence. In March 1933, the Minneapolis Weather Bureau reported that the "amount of dust...at this period was so great as to cause considerable annoyance, as well as being the principal factor in a marked increase in physical ailments, particularly those of the respiratory organs" (St. Martin, 2013). November 1933 saw a nationwide dust event. The Minneapolis Tribune reported that "the dust was so thick that artificial lights were necessary in the daytime" (St. Martin, 2013). More dust storms were reported in spring 1934, spring 1935, fall 1936, fall 1937, and spring 1939. Characteristics of the storms included gale force winds, daytime darkness, destruction of newly seeded or emerging crops, traffic disruption and dust sifting into homes and businesses, often damaging equipment, merchandise and furnishings (St. Martin, 2013). Farming practices implemented since the 1930s to reduce soil erosion and dust help reduce the risk of experiencing these same events today. However, during the historic 1988 drought, "blowing dust in the Red River Valley created scenes reminiscent of the Dust Bowl years" (DNR, 1989), reminding Minnesotans that extreme drought and strong winds can still create dust storms and affect respiratory health, especially in persons with preexisting health conditions, young children, and older adults.Extended drought may affect food security through reduced crop, dairy and livestock production. The historic 1988 drought caused significant agricultural losses in Minnesota, with an estimated loss to the state's economy of $1.2 billion (DNR, 1989). More recently, Midwest drought conditions in 2012 resulted in significantly lower yields of corn and soybeans, both key U.S. crops. The lost income from reduced agricultural production affects farmers with tight margins, threatening their livelihoods.

Hydrologic drought can result in lower water levels and water quality. Minnesotans get their drinking water from both surface water (e.g., Mississippi River) and approximately 400,000 drinking water wells across the state (MDH, 2012). Recurring drought can lower surface water levels and reduce infiltration and recharge to groundwater. In 1988, communities in central and northwestern Minnesota were compelled to purchase water from neighboring towns when their water supplies – both ground and surface water sources – grew dangerously low (DNR, 1989).

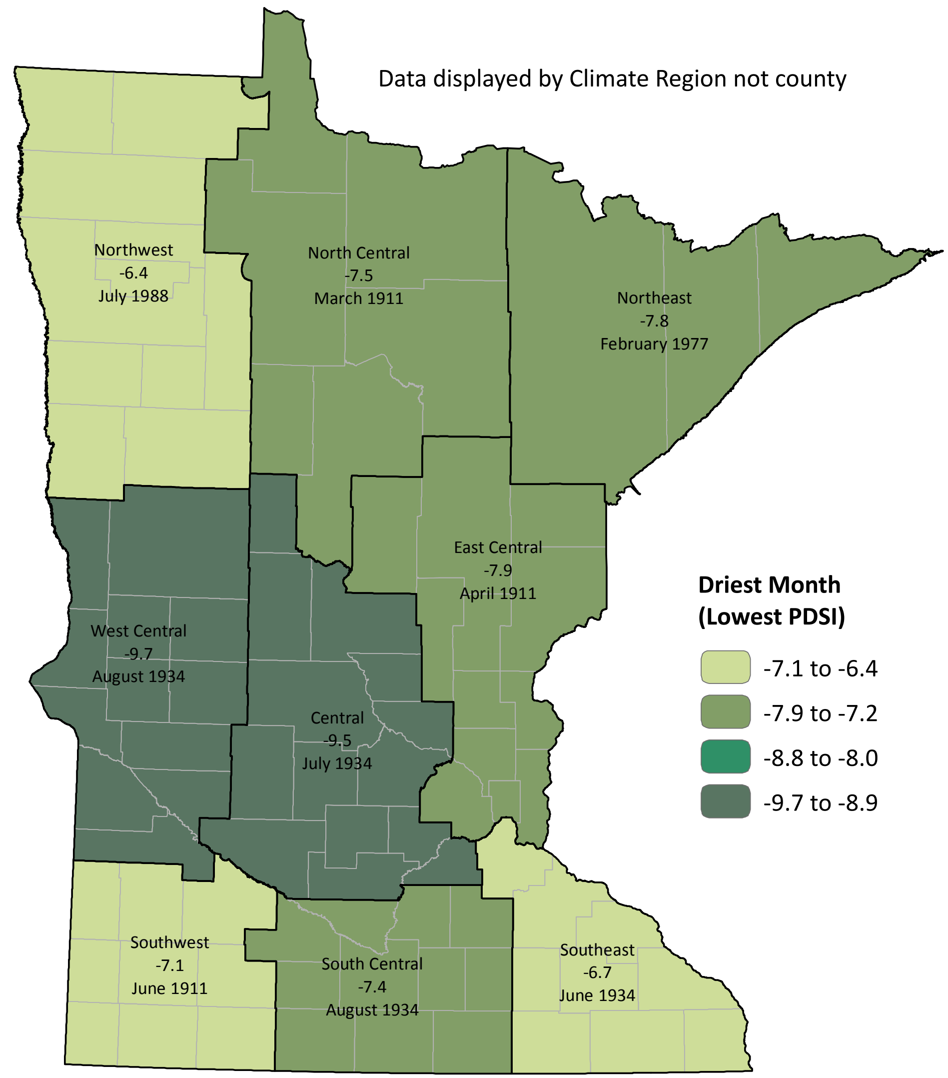
Lower surface water levels also may affect water quality due to a concentration of pollutants. Additionally, increased temperatures may result in harmful algal blooms (MPCA, 2011). Recreation in waters with higher concentrations of pollutants or harmful algal blooms can result in severe illness (Bates et al., 2008).

Drought in Minnesota

Drought can be described by its severity, frequency and duration. The following figures use data from the NOAA National Climactic Data Center to describe the history of drought in Minnesota. Figure VIII-1 shows the lowest recorded PDSI in the history of Minnesota's weather record 1895 – 2012 by climate region. Climate regions are statistical geographic areas created by NOAA in each state to allow for consistent comparison across long periods of time and spatial regions.

The driest conditions ever experienced were in West Central and Central Minnesota climate regions in the summer of 1934, during the height of the Dust Bowl; PDSI values were -9.7 and -9.5, respectively. The Dust Bowl also was the same time that the South Central and Southeast climate regions experienced their lowest PDSI values, of -7.4 and -6.7, respectively. East Central, North Central and Southwest climate regions experienced their lowest PDSI values during a drought in 1911, with values of -7.9, -7.5, and -7.1, respectively. Northeast Minnesota experienced its lowest drought value of -7.8 in February 1977. Northwest Minnesota experienced its lowest drought value of -6.4 in July 1988.

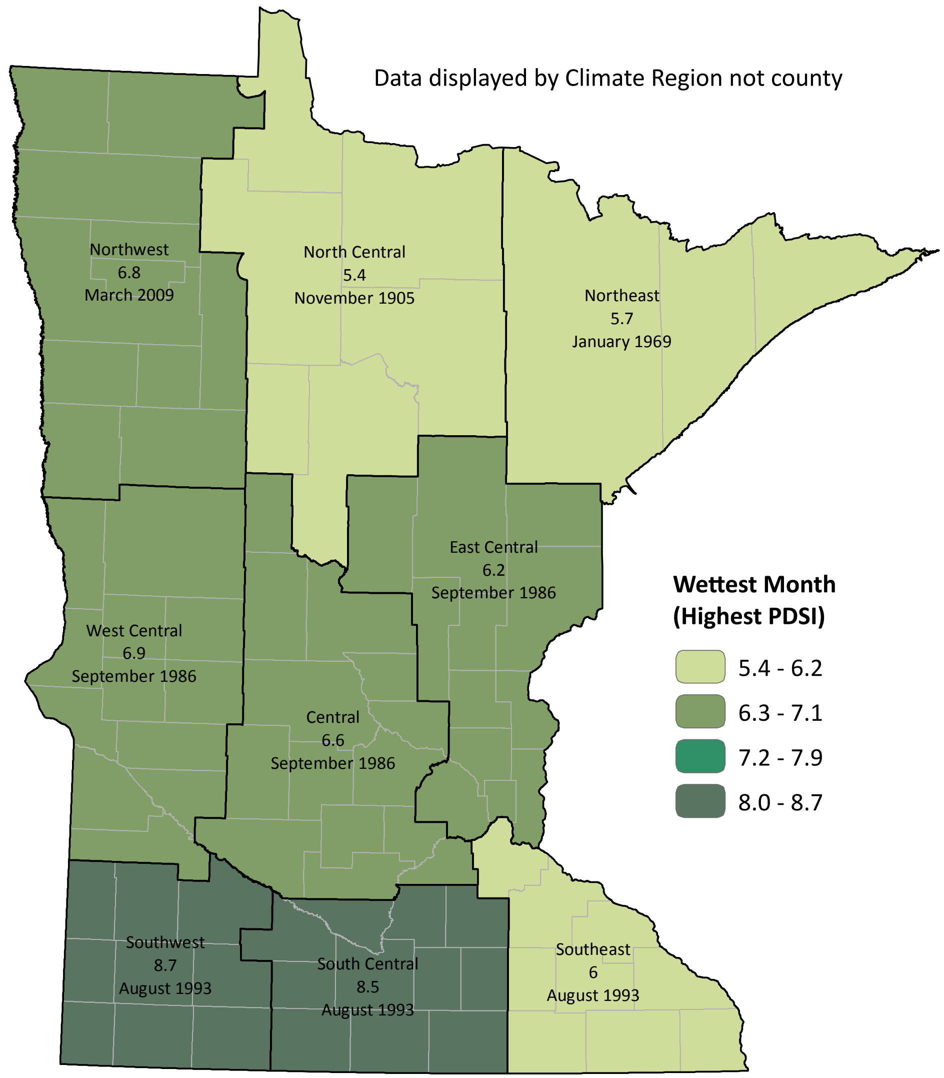
FIGURE VIII-1: DRIEST MONTH ON RECORD 1895 - 2012



Data source: NOAA national Climatic Data Center Historical Palmer Drought Indices

Climate regions experiencing the most extreme drought are not always the driest. Figure VIII-2 shows the highest recorded PDSI for the climate regions in Minnesota. The climate region that experienced the lowest PSDI also had the third highest PDSI – West Central. The two most extreme wet regions were Southwest and South Central in August 1993, with PDSI of 8.7 and 8.5, respectively. August 1993 also was the wettest month for the Southeast region and occurred simultaneous with the Great Flood of 1993, which was caused by late spring snowfall and constant precipitation throughout the summer months (DNR, 1995). The flood resulted in loss of life, homelessness, and billions of dollars in damage to crops and infrastructure (DNR, 1995). September of 1986 was the wettest month for West Central, Central and East Central Minnesota. March 2009 was the wettest month for Northwest Minnesota. The Northeast and North Central had the least extreme wet PDSI; Northeast Minnesota had a PDSI of 5.7 in January 1969 and North Central had a PDSI of 5.4 in November 1905.

FIGURE VIII-2: WETTEST MONTH ON RECORD 1895 - 2012



Data source: NOAA national Climatic Data Center Historical Palmer Drought Indices

Figure VIII-3 shows the percentage of months between 1895 and 2012 where the PDSI was less than or equal to -2 (moderate to extreme drought). The frequency of moderate to extreme drought ranges by climate region from approximately 25% (one in every four months) in the Southwest to 13% (one in every seven and a half months) in the Northeast.

Figures VIII-4.1 through VIII-4.9 show the number of months of moderate to extreme drought annually in light green, the 10-year rolling average in dark green, and the linear trend line from 1895 – 2012 by climate region. Each figure demonstrates considerable year-to-year variability in the number of months with moderate to extreme drought. However, all nine figures show a peak in moderate to extreme drought in the 10-year average line the late 1930's, corresponding with the Dust Bowl.

FIGURE VIII-4.1: MODERATE TO EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 1

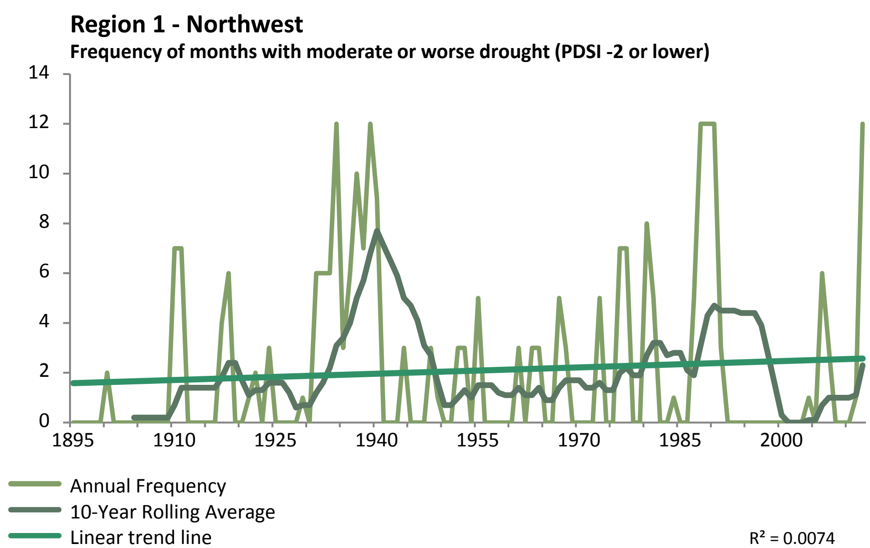
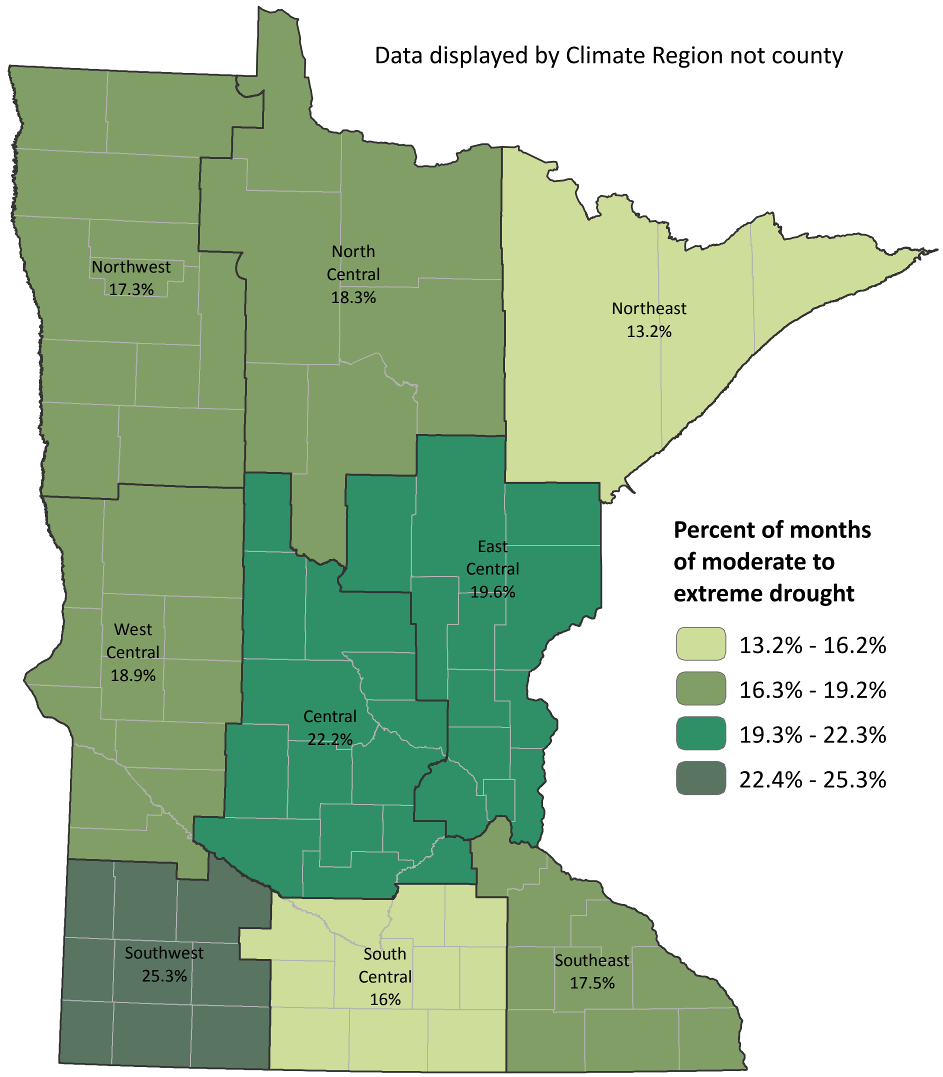


FIGURE VIII-3: PERCENT OF MONTHS OF MODERATE TO EXTREME DROUGHT 1895 - 2012



Data source: NOAA national Climatic Data Center Historical Palmer Drought Indices

FIGURE VIII-4.2: MODERATE TO EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 2

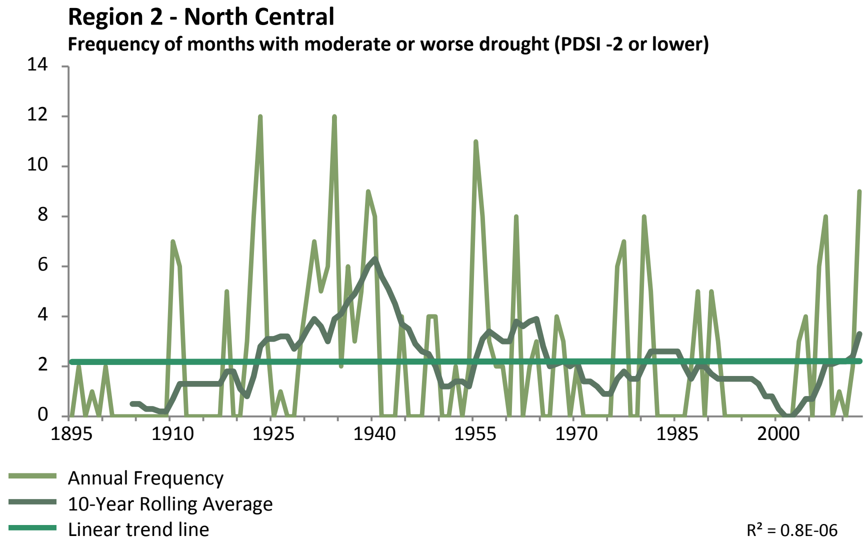


FIGURE VIII-4.3: MODERATE TO EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 3

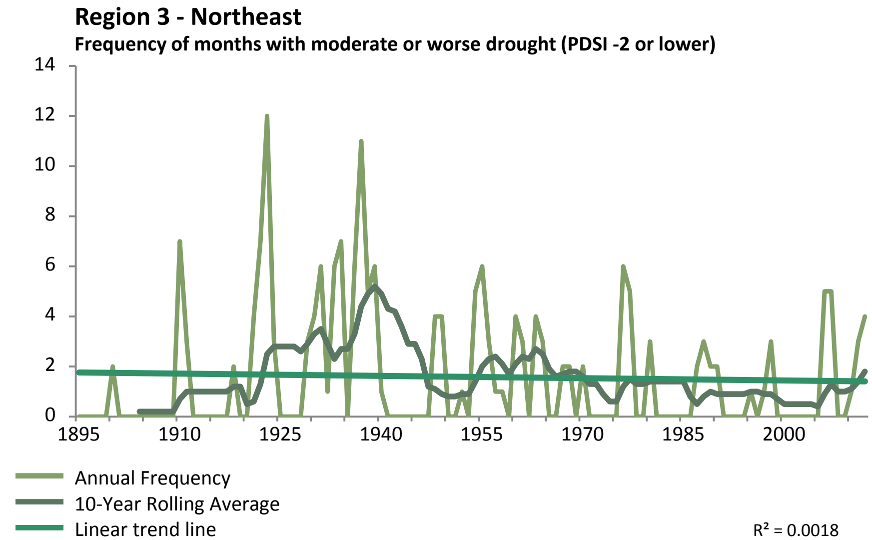


FIGURE VIII-4.4: MODERATE TO EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 4

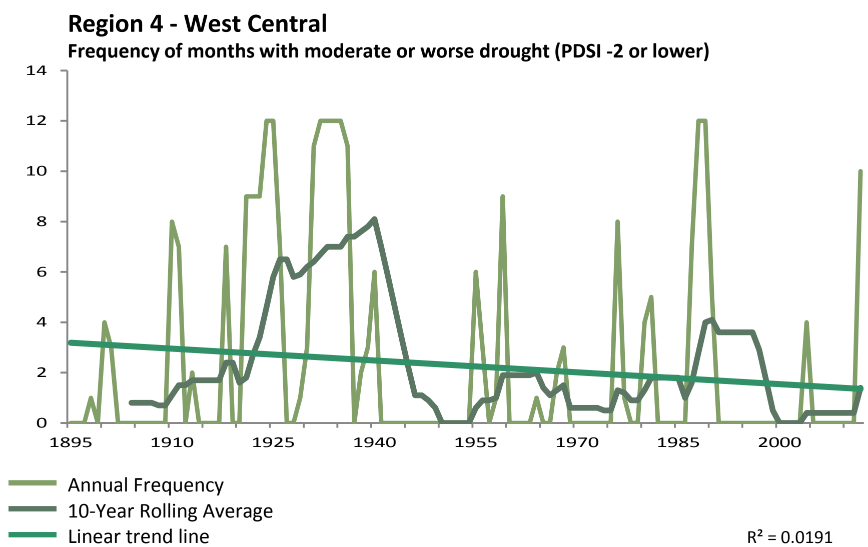


FIGURE VIII-4.5: MODERATE TO EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 5

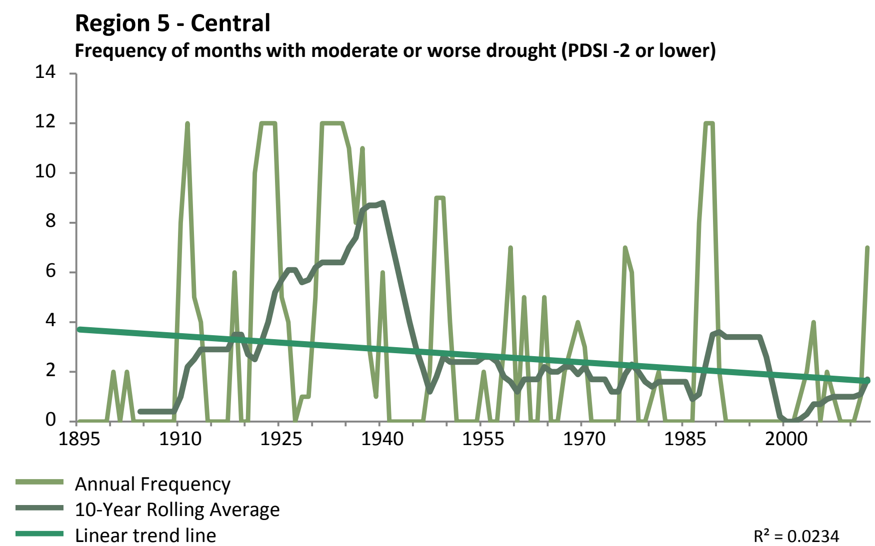


FIGURE VIII-4.6: MODERATE TO EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 6

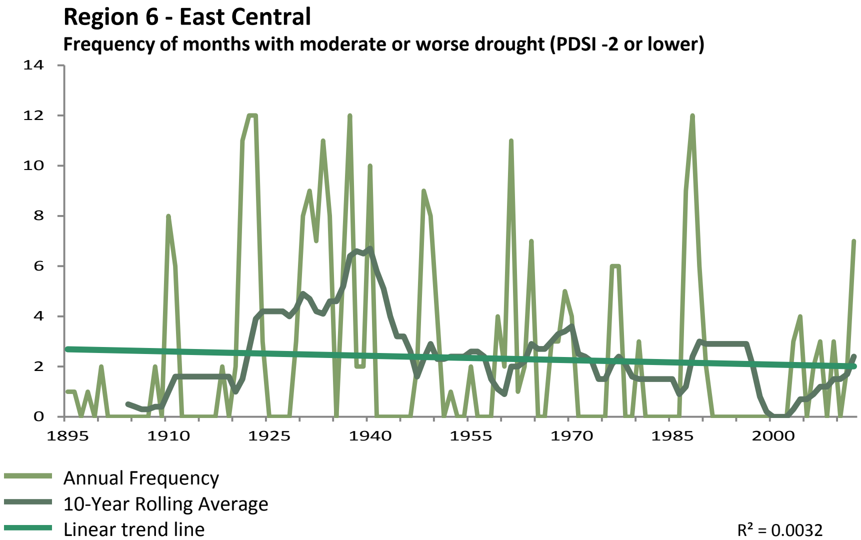


FIGURE VIII-4.7: MODERATE TO EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 7

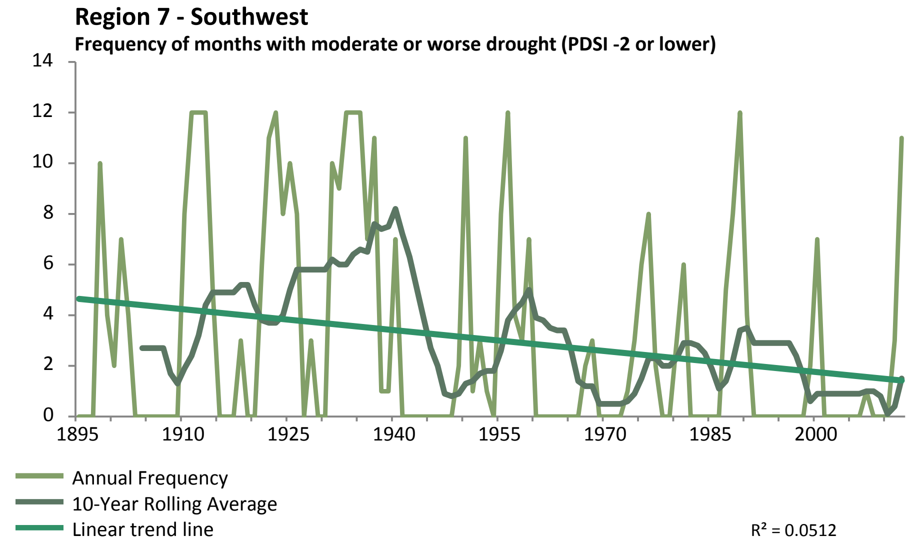


FIGURE VIII-4.8: MODERATE TO EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 8

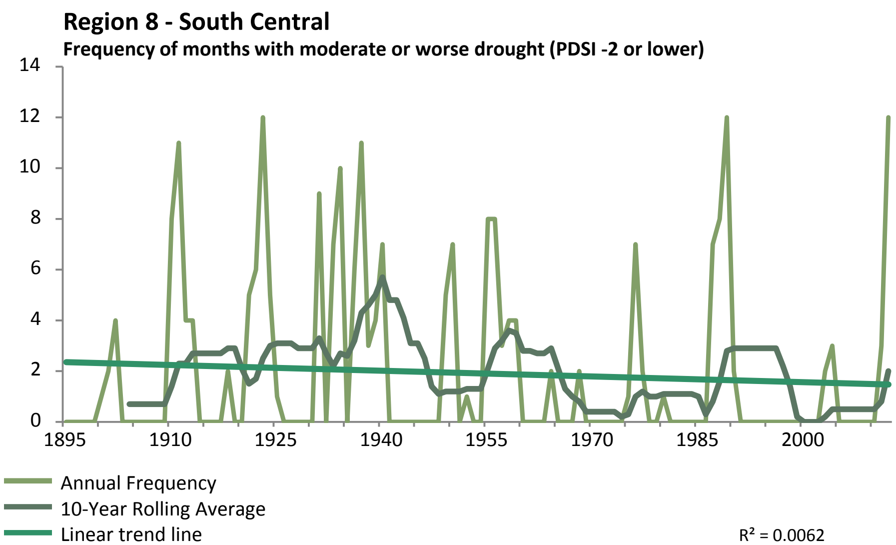


FIGURE VIII-4.9: MODERATE TO EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 9

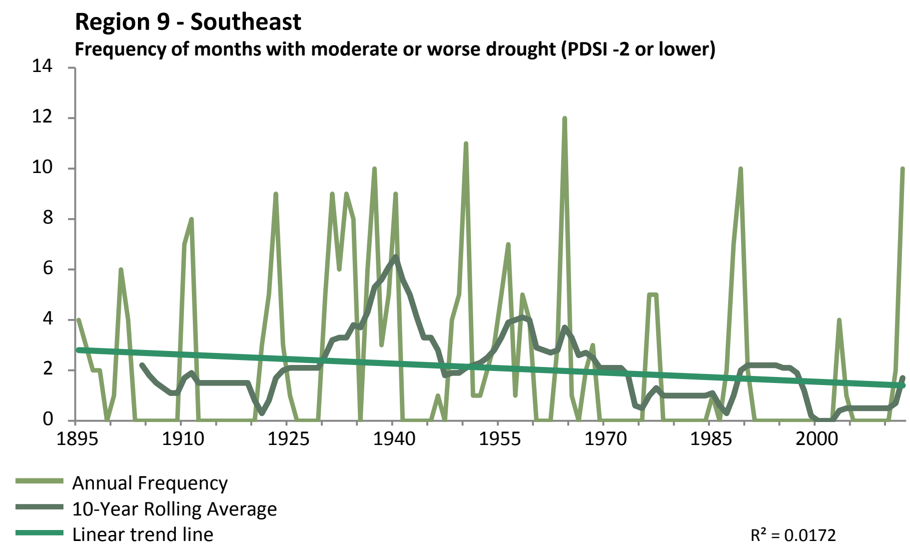


Figure VIII-5 shows percentage of months between 1895 and 2012 where the PDSI was less than or equal to -4 (extreme drought) by climate region. The frequency of extreme drought by climate region ranges from 6.6% (one in every 15 months) in the Central climate region to 2.5% (one in every 40 months) in the Northeast climate region.

Figures VIII-6.1 – VIII-6.9 show the number months of extreme drought annually in light green, the 10-year rolling average in dark green, and the linear trend line from 1895 – 2012 by climate region. As with the charts for moderate to extreme drought, there is considerable variability from year to year. There were few years with the majority of months experiencing extreme drought. Only Central and West Central regions had at least one year where all 12 months were in extreme drought, occurring during the peak of the Dust Bowl.

FIGURE VIII-6.1: NUMBER OF MONTHS OF EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 1

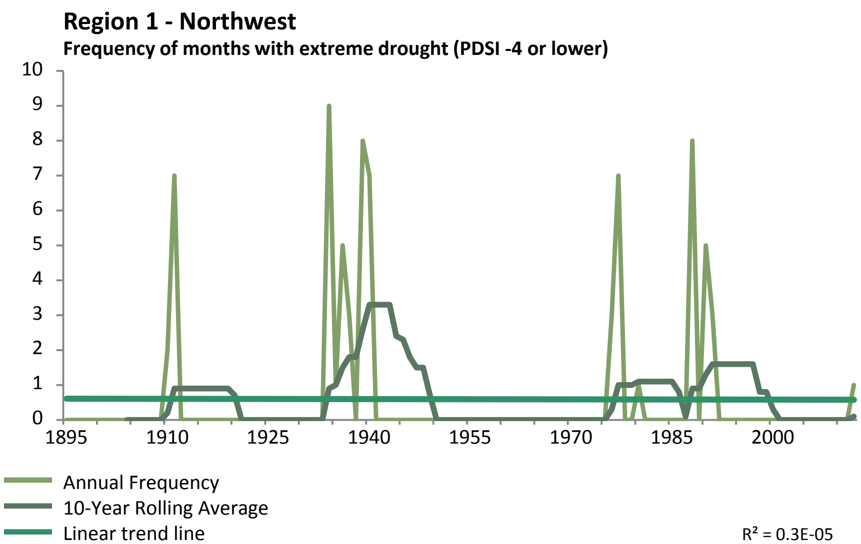
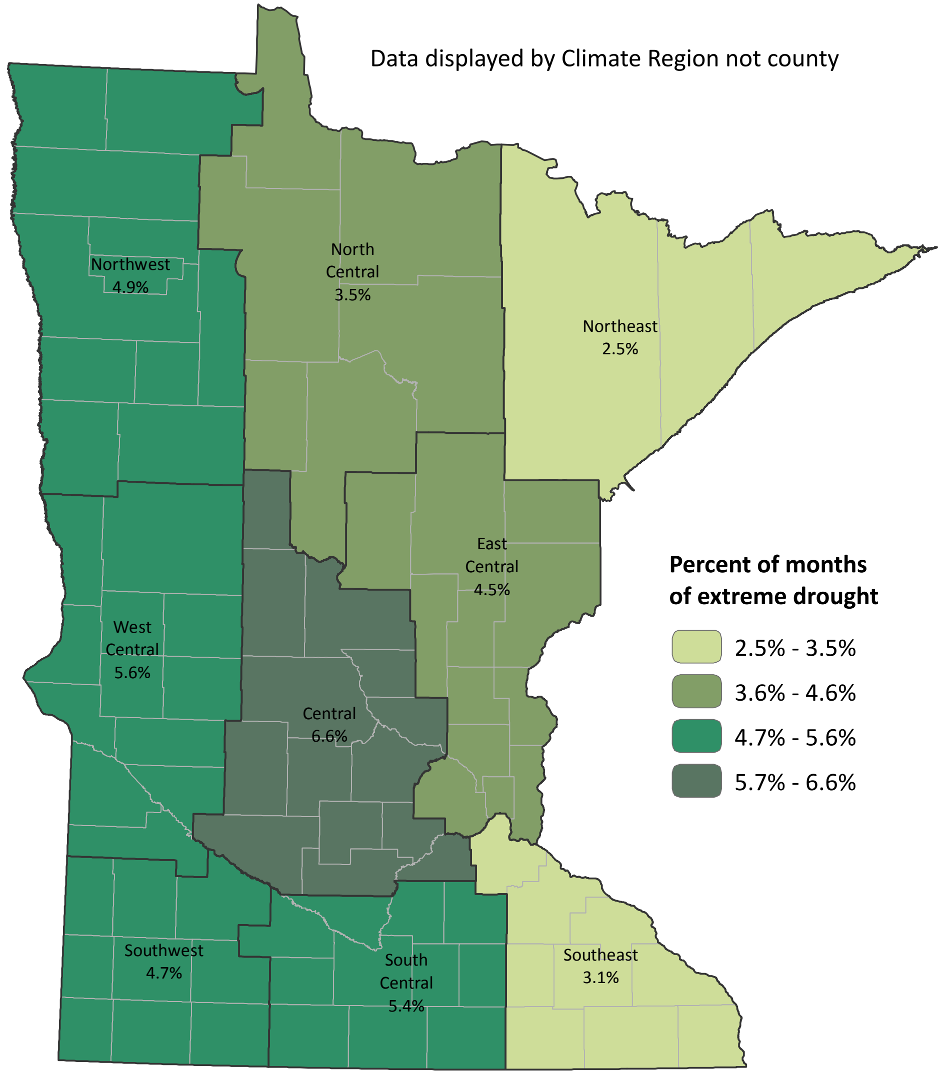


FIGURE VIII-5: PERCENTAGE OF MONTHS OF EXTREME DROUGHT 1895 - 2012



Data source: NOAA national Climatic Data Center Historical Palmer Drought Indices

FIGURE VIII-6.2: NUMBER OF MONTHS OF EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 2

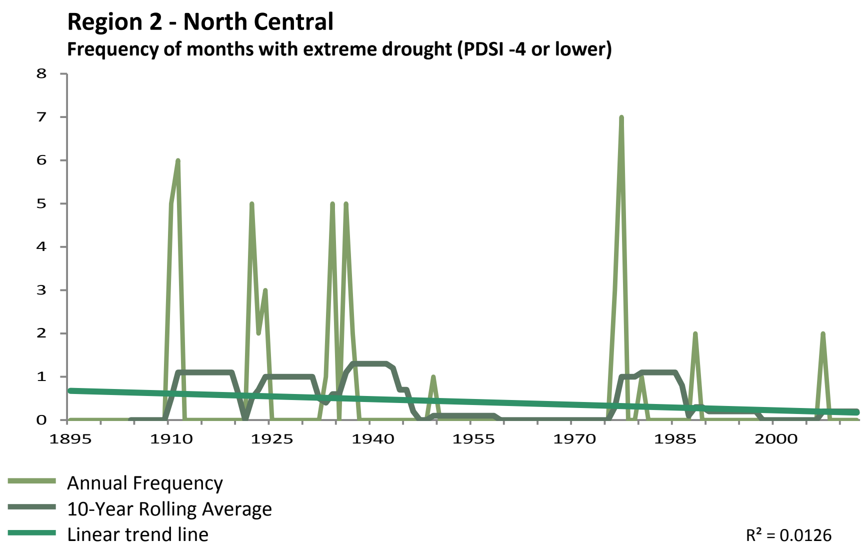


FIGURE VIII-6.3: NUMBER OF MONTHS OF EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 3

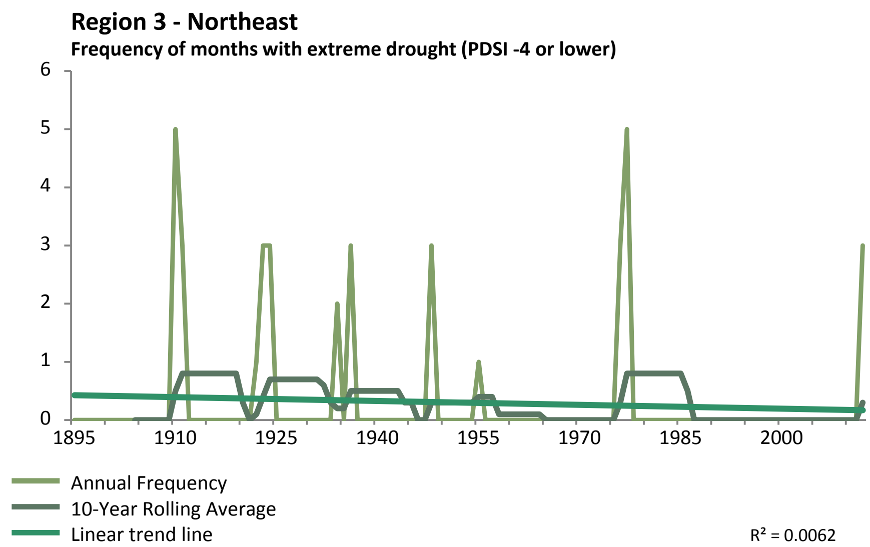


FIGURE VIII-6.4: NUMBER OF MONTHS OF EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 4

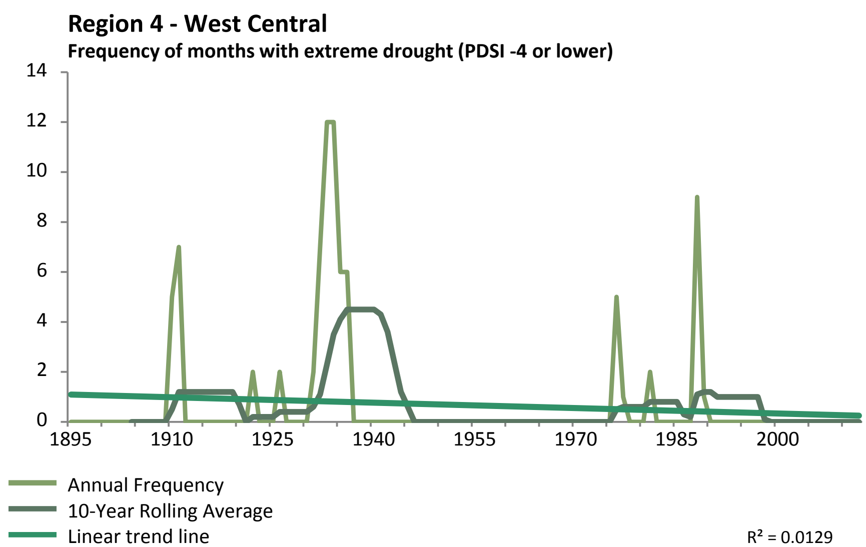


FIGURE VIII-6.5: NUMBER OF MONTHS OF EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 5

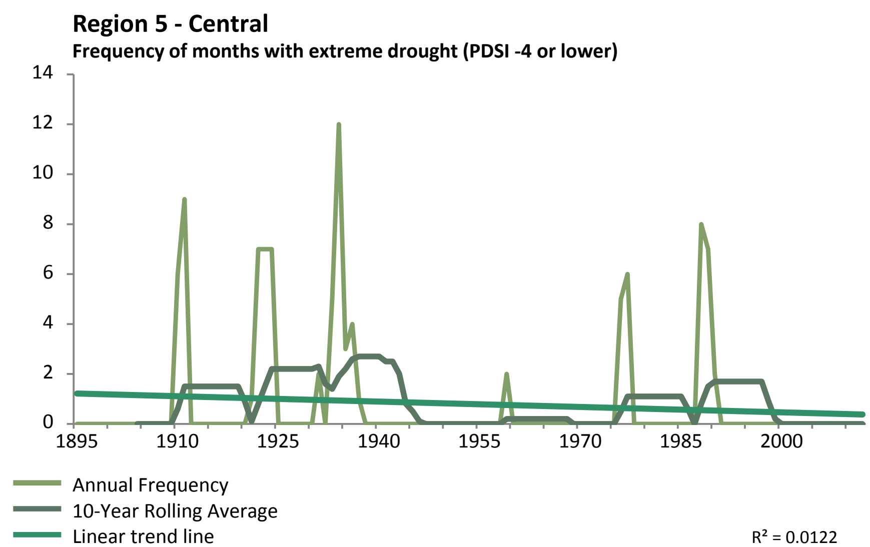


FIGURE VIII-6.6: NUMBER OF MONTHS OF EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 6

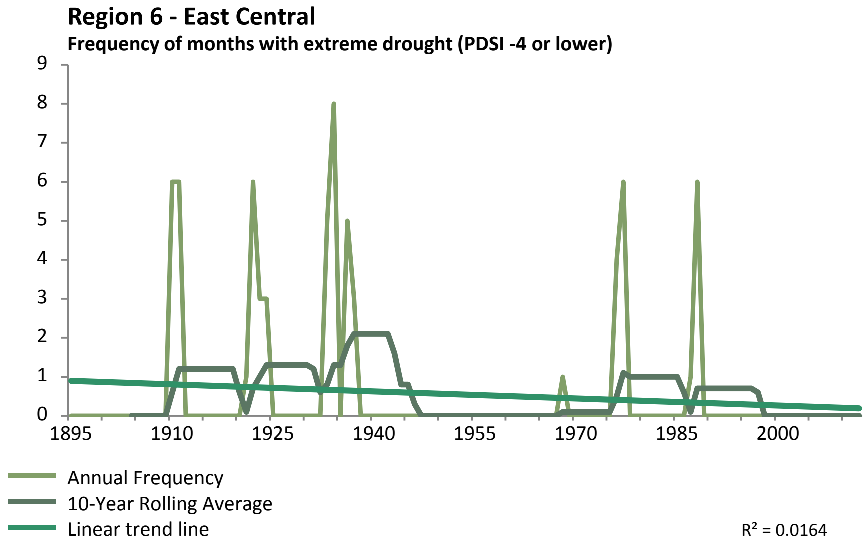


FIGURE VIII-6.7: NUMBER OF MONTHS OF EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 7

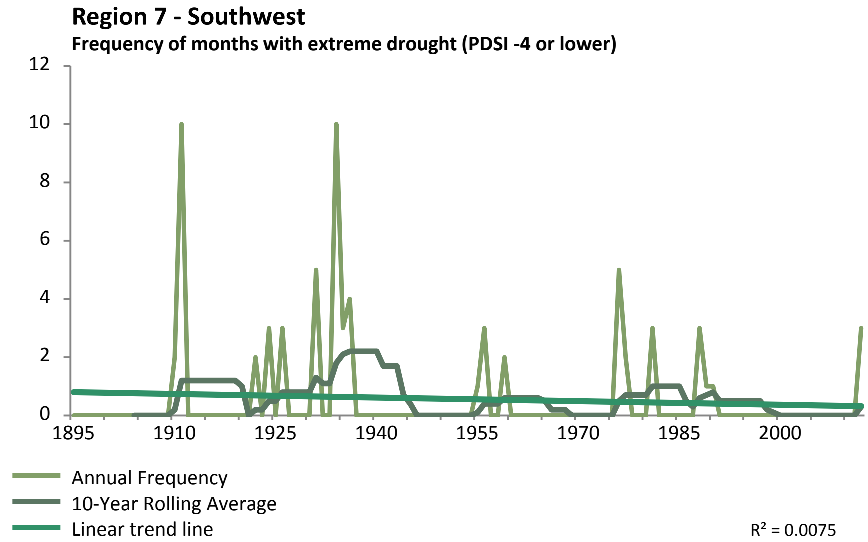


FIGURE VIII-6.8: NUMBER OF MONTHS OF EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 8

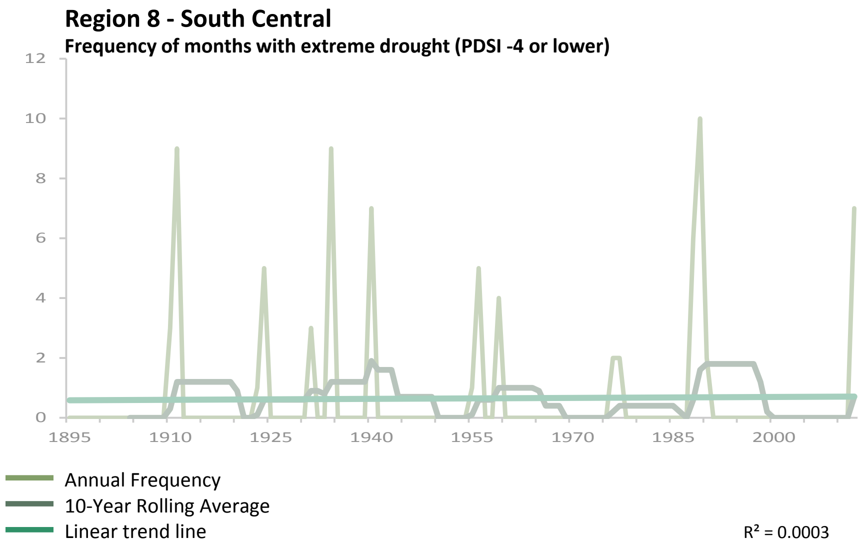
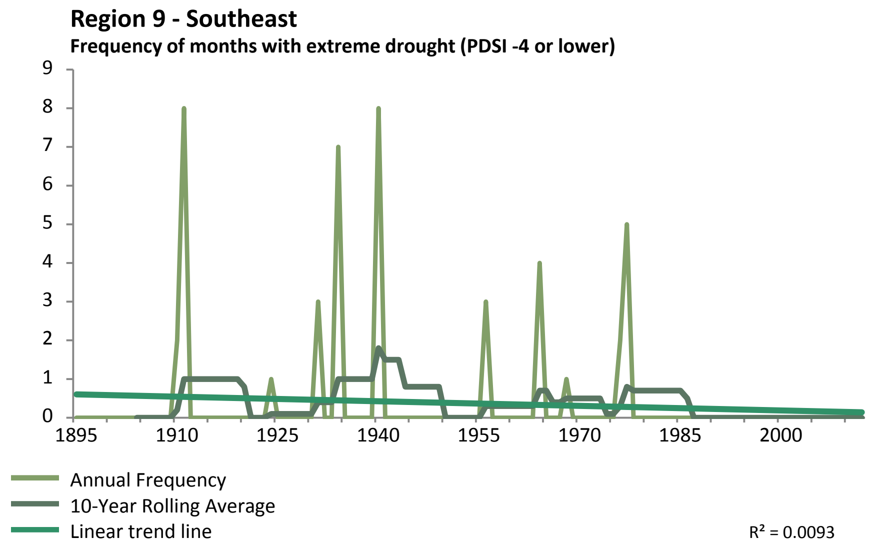


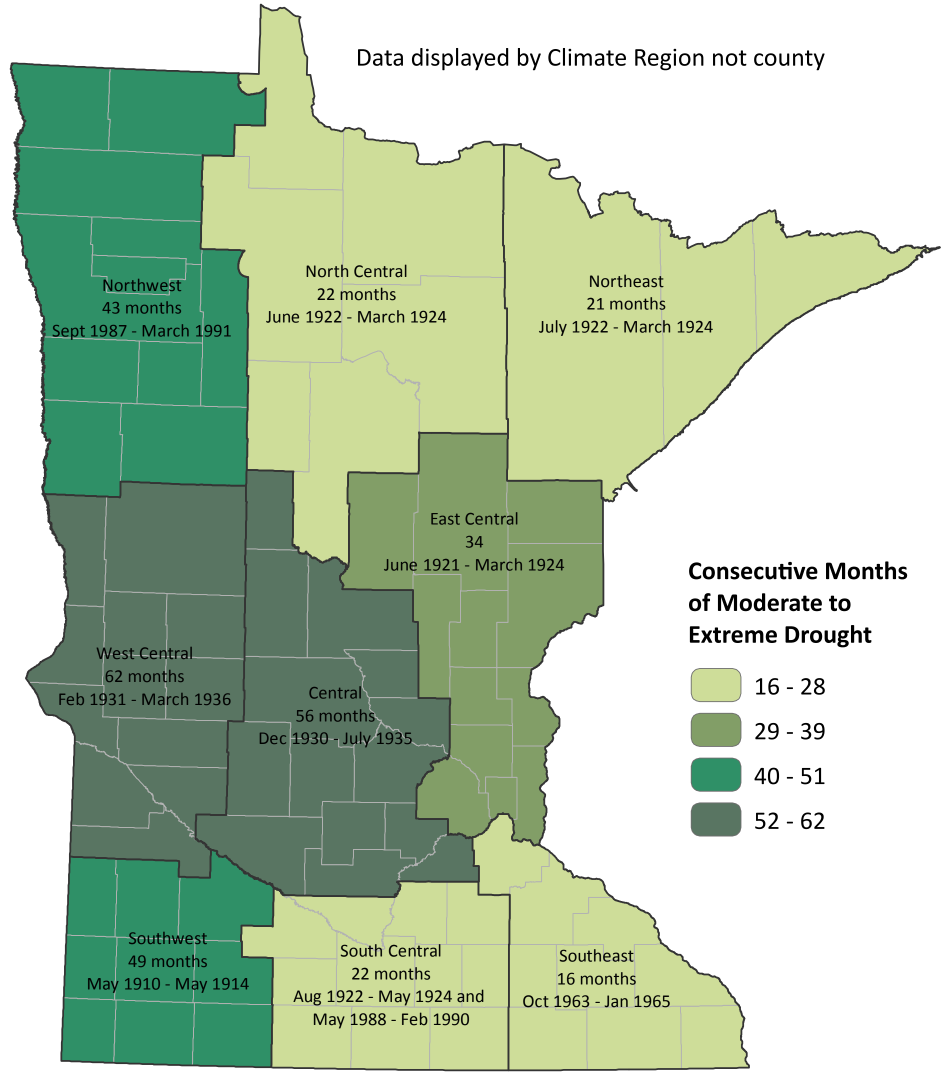
FIGURE VIII-6.9: NUMBER OF MONTHS OF EXTREME DROUGHT 1895 - 2012, CLIMATE REGION 9



Understanding the duration of drought is important for maintaining an adequate water supply for agriculture, power generation, industry and human consumption. Figure VIII-7 shows the longest duration of moderate to extreme drought, or PDSI of -2 or lower, by climate region. The regions are labeled with the number of months of the longest moderate to extreme drought and when the drought occurred. West Central and Central regions experienced the longest duration of moderate to extreme drought.

In West Central the longest moderate to extreme drought was 62 months long between February 1931 and March 1936. The Central region experienced a moderate to extreme drought 56 months long from December 1930 to July 1935. Southwest and Northwest regions experienced the next longest runs of moderate to extreme drought, 49 months and 43 months, respectively. The Southwest moderate to extreme drought occurred from May 1910 through May 1914 while the Northwest moderate to extreme drought occurred from September 1987 to March 1991. The East Central region experienced a moderate to extreme drought for 34 months between June 1921 and March 1924. The North Central and Northeast regions' longest moderate to extreme droughts were 22 months and 21 months respectively, from summer 1922 through spring 1924. South Central experienced a moderate to extreme drought of 22 months during the same time period, and another 22-month drought from May 1988 through February 1990. The Southeast region experienced the shortest moderate to extreme drought, lasting only 16 months from October 1963 to January 1965.

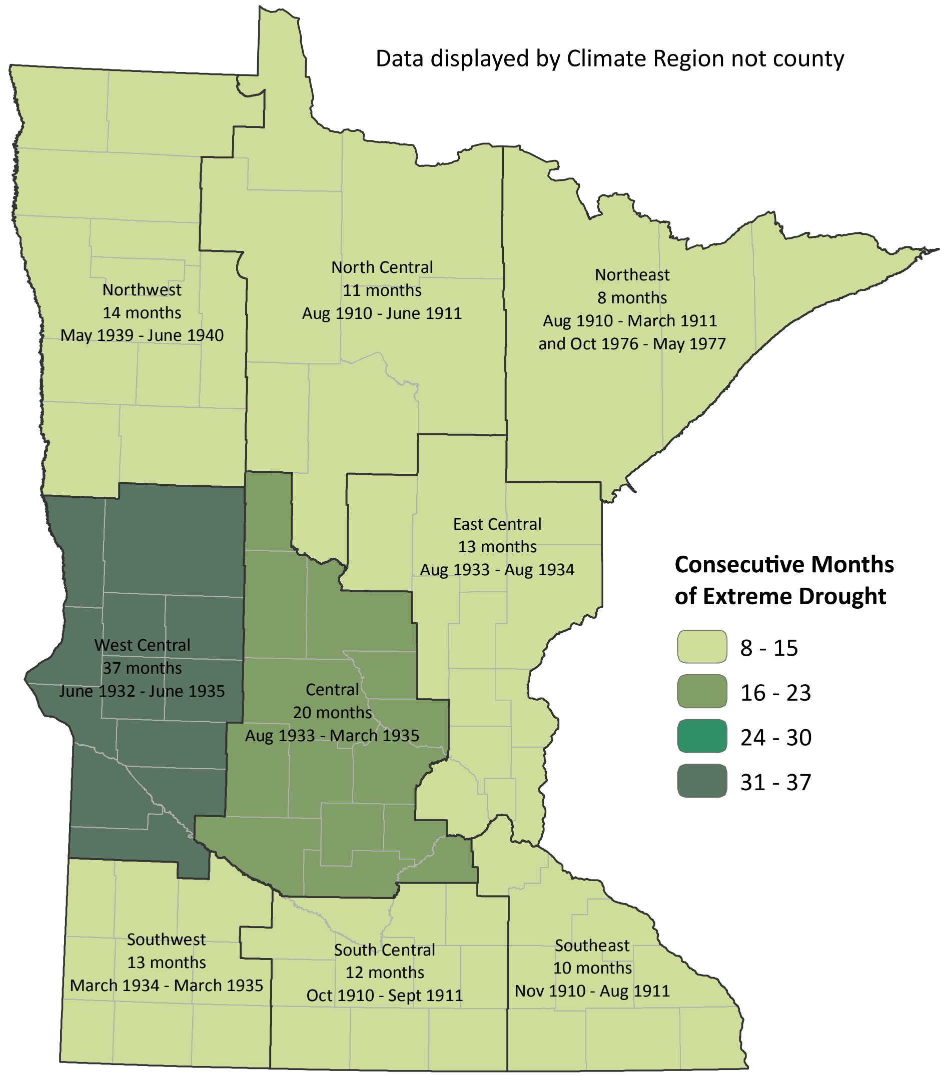
FIGURE VIII-7: LONGEST RUN OF MONTHS OF MODERATE TO EXTREME DROUGHT 1895 - 2012



Data source: NOAA national Climatic Data Center Historical Palmer Drought Indices

Figure VIII-8 shows the longest duration of extreme drought, or PDSI of -4 or lower, by climate region. The regions are labeled with the number of months of the longest extreme drought and when the drought occurred. West Central stands out starkly with the longest extreme drought, lasting 37 months from June 1932 to June 1935. The Central region had the second longest extreme drought, lasting 20 months from August 1933 to March 1935. The rest of the regions had an extreme drought lasting approximately one-year. In the Northwest, Southwest and East Central regions, the longest extreme droughts took place during the Dust Bowl or shortly thereafter. In the North Central, South Central, Southeast and Northeast, the longest extreme droughts took place between 1910 and 1911. The Northeast region had two equally long extreme droughts, between August 1910 to March 1911 and October 1976 to May 1977. Each lasted eight months, shorter than any other region's extreme drought.

FIGURE VIII-8: LONGEST RUN OF MONTHS OF EXTREME DROUGHT 1895 - 2012



Data source: NOAA national Climatic Data Center Historical Palmer Drought Indices

Table VIII-1 provides a succinct snapshot of some of the variability among climate regions in the state. On average, all climate regions in the state were wetter than the PDSI expected for the period, expressed by the positive average PDSI values. PDSI measures departures of precipitation from the expected, which in theory should sum to zero.

The Central region's average PSDI was closest to zero (0.11 PDSI), the driest of the nine regions on average. The Central region had the second lowest minimum PDSI and the highest frequency (percent of months) of extreme drought. The Northwest region's average PSDI was the farthest from zero (0.83 PDSI), the wettest on average of the nine regions. The Northwest region had moderate values for both the minimum and maximum PDSI but still experienced significant variability; based on the standard deviation it was the second most variable region. The Southwest region was the most variable, indicated by the largest standard deviation of the nine regions. The Southwest region had both the highest maximum (wettest) PDSI, and conversely the highest frequency (percent of months) of moderate to extreme drought. The West Central region had the lowest (driest) PDSI and the longest run of both moderate to extreme and extreme drought, but on average was still not as dry as the Central region.

TABLE VIII-1: PALMER DROUGHT SEVERITY STATISTICS BY CLIMATE REGION 1895 - 2012

Climate Region	Average PDSI	Standard Deviation	Maximum PDS	Date of Maximum PDSI	Minimum PDSI	Date of Minimum PDSI
Northwest (1)	0.83	2.66	6.85	March 2009	-6.36	July 1988
North Central (2)	0.37	2.31	5.41	November 1905	-7.47	March 1911
Northeast (3)	0.21	2.02	5.68	January 1969	-7.75	February 1977
West Central (4)	0.27	2.60	6.86	September 1986	-9.7	August 1934
Central (5)	0.11	2.63	6.65	April 1924 & September 1986	-9.5	July 1934
East Central (6)	0.12	2.33	6.25	September 1986	-7.92	April 1911
Southwest (7)	0.18	2.69	8.72	August 1993	-7.1	June 1911
South Central (8)	0.47	2.48	8.48	August 1993	-7.41	August 1934
Southeast (9)	0.28	2.23	6.05	August 1993	-6.74	June 1934

Populations Vulnerable to Drought

Drought can result in negative health outcomes, particularly related to impacts to air quality. Young children, older adults and persons with respiratory conditions, such as asthma, are more vulnerable to negative health effects from wildfire smoke and ash and dust kicked up from dry fields by strong winds. Drought also has indirect impacts, such as on people's livelihoods and communities depended on agriculture, or on regional systems for power production. If an extreme drought occurs similar to that of the 1930s Dust Bowl, children, elderly and those with specific health conditions would experience the worst direct health impacts.

Figure IV-7 in Chapter IV shows the percentage of population less than five years old by county. The map shows there are higher total counts and percentages of young children in the Twin Cities and surrounding counties where there has been a higher frequency of extreme drought, longer periods of drought, and larger amounts of agricultural land that could experience dust storms. Also, there are higher percentages of young children in northwestern Minnesota, in Mahnomen and surrounding counties where they may have increased vulnerability to negative health outcomes of potential forest fire emissions during drought conditions.

Figure IV-5 in Chapter IV shows the percentage of persons who are 65 years old and over by county. Percentages of older adults are highest in western Minnesota counties of Traverse, Big Stone, Laq Qui Parle, Grant, Lincoln and Murray where drought has occurred at greater extremes, more frequently and with longer duration. High percentages of older adults in Kittson County in the northwest, and Aitkin and Lake counties in the northeast may be vulnerable to negative health outcomes from the emissions of drought-induce wildfires.

Figures V-6 and V-7 in Chapter 5 show asthma emergency department (ED) visit rates and hospitalization rates, respectively, and Figure V-8 shows COPD hospitalization rates by county. This data demonstrates the population with existing respiratory disease that will be more vulnerable to negative health impacts from air quality issues as a result of extreme drought conditions. Mille Lacs, Benton and Kanebec counties consistently had higher rates of asthma ED visits, asthma hospitalizations and COPD hospitalizations. Mille Lacs had the highest rate for asthma ED visits (85 per 10,000 persons in the population) and the second highest rate for both asthma (13 per 10,000) and COPD (78 per 10,000) hospitalizations. Benton had the highest rate of asthma hospitalizations (13 per 10,000), and Clearwater had the highest rate of COPD hospitalizations (91 per 10,000). Air pollutants in this region as a result of drought are more likely to be from forest fires than agriculture. The highest number of asthma ED visits, asthma hospitalizations and COPD hospitalizations occurred in Hennepin County, followed by Ramsey, Dakota and Anoka counties, due to the larger populations in the metropolitan counties. St. Louis County had the third highest count of COPD hospitalizations, after Hennepin and Ramsey counties. The urban regions may be less likely to have air quality impacts from drought-induced wildfires and agricultural dust depending on the weather patterns and how far the particles drift.

Direct and indirect impacts of drought may disproportionately affect persons of color. Direct impacts, such as worsened air quality, may exacerbate respiratory conditions that have a higher prevalence in persons of color, particularly blacks/African Americans and American Indians, in Minnesota. Indirect impacts may include damage to wild rice crops and "loss of tree and plant species important for Native artistic, cultural, and economic purposes, including tourism" (Bennet et al., 2014). See Figure IV-9 in Chapter IV for the distribution of persons of color in Minnesota.

Effects of Climate Change on Drought

Future impacts of climate change on precipitation and drought are less certain than changes in temperature. While the overall trend is projected to be a slight increase in total annual precipitation, annual variability will likely increase more (Pryor et al., 2014). How and where precipitation falls may have a greater impact on drought than the total amount of precipitation. Precipitation may become more episodic, where it will drench some areas and cause flooding, while other areas will experience localized drought.

Models show that precipitation in the winter will increase, with more precipitation falling as rain or mixed precipitation rather than snow (Collins et al., 2013; Pryor et al., 2014). Increased rain during the winter over frozen ground and reduced snowpack for spring melt can decrease infiltration into groundwater resources or into soil for crops (Sinha & Cherkauer, 2010). Warmer springs will likely advance the timing of snowmelt runoff earlier into the year. The ability of soils to absorb this moisture will depend on how frozen or compacted the soil is at that time. If soils are able to absorb and retain more of this moisture, soil moisture could be higher at the outset of the growing season. Alternatively, if this moisture is lost to runoff, land could be more likely to enter the growing season with a moisture deficit (USDA, 2010).

While no apparent change in drought duration occurred in the Midwest during the past century, some models project decreased precipitation and higher temperatures during the summer in the future (Pryor et al., 2014). Increased temperature can result in increased evapotranspiration. As a result, higher summer temperatures may lead to increased demand for water by agricultural crops and forests. During a drought the ability to meet water demand could diminish. These climate changes may impact crops and forests; power generation, which relies on significant supplies of water for cooling; barging and shipping in the Great Lakes and Mississippi River; and the quantity and quality of water supplies for native cold water fish, human consumption and recreation.

Image courtesy of Wikimedia Commons

IX Overall Population Vulnerability and Climate Hazard Risks

In order to better understand the overall number of climate hazards and vulnerable populations by county, MDH created two summary maps. The Composite Climate Hazard Risk Map describes counties that have experienced the greatest number of climate hazards. The Composite Population Vulnerability Map describes the counties that have the greatest percentages of vulnerable populations. Both maps are described in more detail on the next pages.

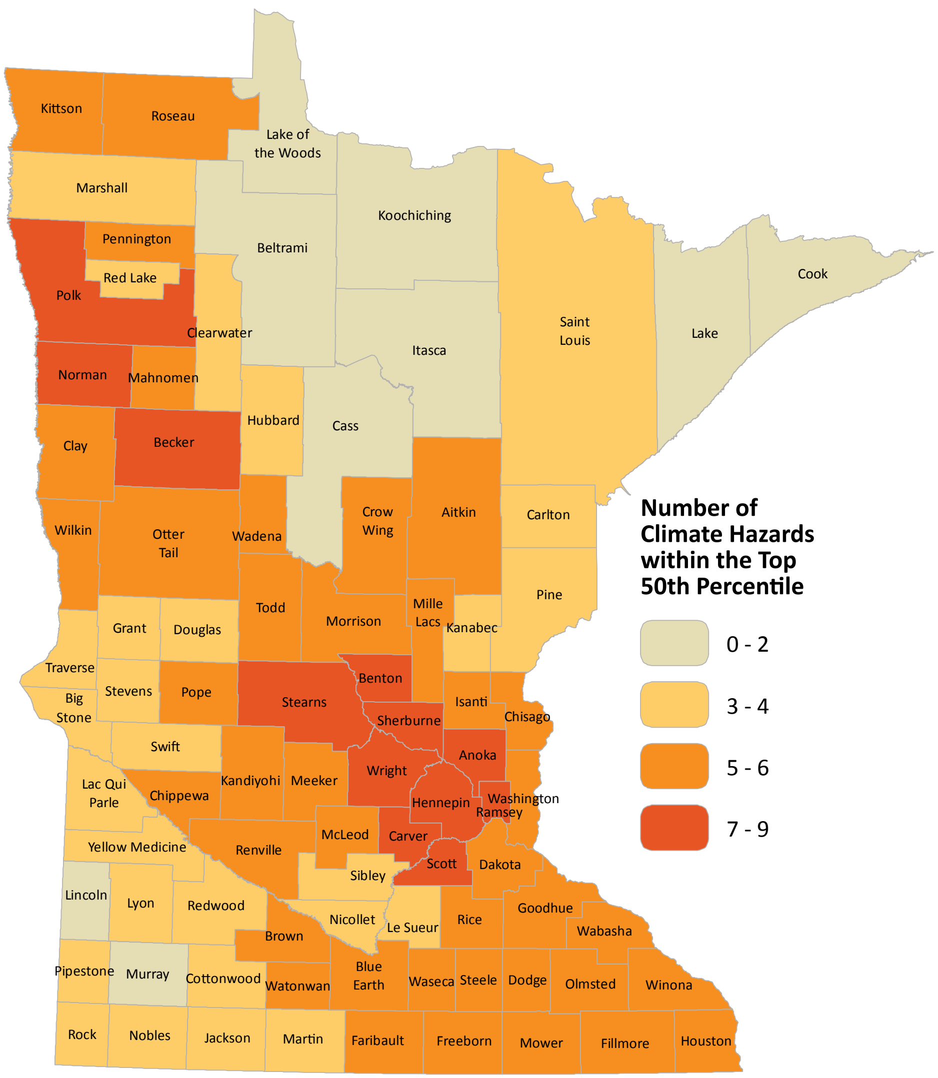
Composite Climate Hazard Risk Map

The Composite Climate Hazard Risk Map shows the number of climate hazards per county that had more occurrences/incidences than the median, or half of the counties (i.e., 50th percentile). The map includes the following climate hazards: number of extreme heat events, number of days exceeding fine particle pollution air quality standard, number of days exceeding ozone air quality standard, Lyme disease incidence, human anaplasmosis incidence, West Nile virus incidence, number of flood events, number of flash floods, percentage of months of extreme drought, and longest run of months of extreme drought. A score of ten would mean that the county has had all of the climate hazards occur in that county within the top 50th percentile.

All counties had at least one climate hazard occur within the top 50th percentile, except two: Lake and Koochiching counties. Seven counties had one to two climate hazards; 27 counties had three to four climate hazards; 39 counties had five to six climate hazards; and 12 counties had seven to nine climate hazards within the top 50th percentile.

This map shows that almost all counties in Minnesota have been impacted by the climate hazards examined in the report; however, some counties have experienced more climate hazards than others. Because this report does not review all hazards related to climate change nor does it review future risk of these hazards, all counties need to understand, plan and prepare for their changing climate hazard risks.

FIGURE IX-1: COMPOSITE CLIMATE HAZARD RISK



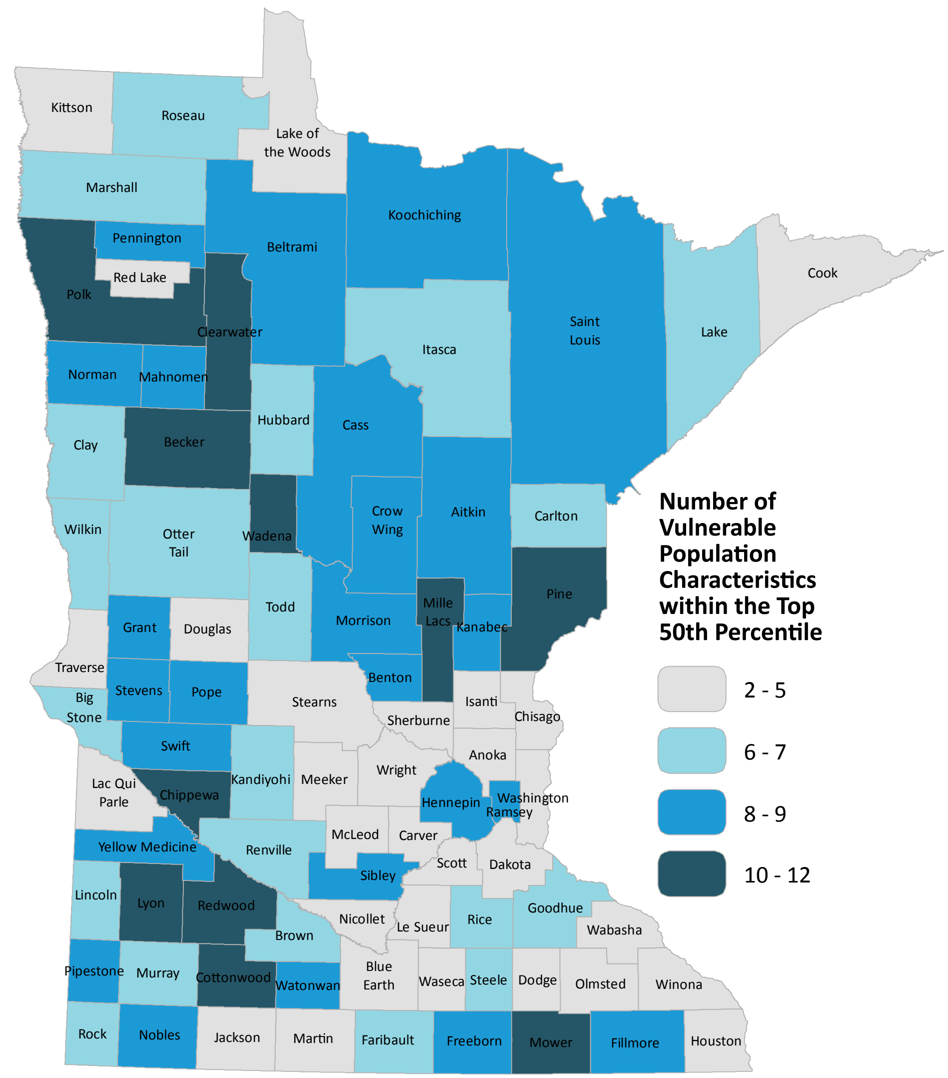
Composite Population Vulnerability Map

The Composite Population Vulnerability Map shows the number of vulnerable populations per county where the percentage of the population with that vulnerability characteristic was greater than the median, or half of the counties (i.e., 50th percentile). The map includes the following vulnerable populations: population 65 years old and older; persons 65 years old and older living alone; population less than five years old; population in poverty; people of color; workers employed in agriculture, forestry, fishing, hunting and mining industries; workers employed in construction industry; asthma emergency department visits; asthma hospitalizations; chronic obstructive pulmonary disease hospitalizations; older adults living below 150 percent of poverty; families with children in poverty; housing units that are mobile homes; households with no vehicles; and limited English proficiency. A score of 15 would mean that the county contains every vulnerable population and all of the populations are within the top 50th percentile.

All counties had at least two vulnerable populations within the top 50th percentile. Thirty counties had two to five vulnerable populations; 21 counties had six to seven vulnerable populations; 25 counties had eight to nine vulnerable populations; and 11 counties had ten to 12 vulnerable populations within the top 50th percentile.

The prevalence of vulnerable populations throughout Minnesota suggests the need for more analyses to better understand the distribution of vulnerable populations within each county. While assessing vulnerable populations at a county level provides some information about the vulnerability of the county, averaging percentages of vulnerable populations over a large geographic area masks areas that may have a concentration of vulnerable populations. MDH encourages all counties to further assess vulnerable populations in their jurisdiction at a finer spatial scale, including by township, city and neighborhood when possible, and many counties and cities have begun to do this. Identifying vulnerable populations in a community will help organizations allocate resources to the populations and areas that are less able to cope with climate hazards. Additionally, MDH only examined vulnerable populations to the climate hazards reviewed in the report and substantiated in the literature. MDH also did not assess future demographic changes. The Composite Population Vulnerability Map represents the first step in understanding population vulnerability within a county.

FIGURE IX-2: COMPOSITE POPULATION VULNERABILITY



Data source: American Community Survey 5-Year Estimtes 2007-2011

X Conclusion

The final section of this report provides a description of the limitations of the study, next steps for the vulnerability assessment and BRACE CDC activities, and a conclusion.

Study Limitations

The vulnerability assessment reviewed the historic weather data and recent population vulnerability for extreme heat, air pollution, vector-borne disease, flooding and drought. Climate models predicting temperature, precipitation and air currents have not been introduced. As a result, the climate vulnerability assessment cannot predict future vulnerability. If one makes the assumption that historic trends will continue, the central part of the state will continue to see the most severe and longest drought, as well as, the highest number of extreme heat declarations and the most poor air quality index days; the southeast will continue to see the most flash floods; and the north-central part of the state will continue to see expansion of tick-borne diseases. But again, past weather conditions do not predict future weather conditions, especially in the face of climate change.

Recent demographic trends also are not a reliable picture of the future reality. Older adults and older adults living alone may continue to be in higher percentages in west-central Minnesota, or the concentration of this population could shift towards urban centers where services and group housing opportunities are available. All counties planning for the health and wellbeing of their populations should review current trends, but also look to models and predictions of future climate risk and population vulnerability to plan accordingly.

Additional limitations of the vulnerability assessment include data availability, data accuracy, data aggregation and geographic display, and lack of validation of the methodology used in the composite vulnerability scores.

DATA AVAILABILITY

A number of data measures that would have been ideal for the vulnerability assessment were either not available or not available yet. For example, knowing the percentage of households with air conditioning is a critically important factor for determining vulnerability to extreme heat. However, only some municipalities collect this information and often it only includes central air conditioning data. An example of data that is not available yet but will be in future years is measures of populations with disabilities. This data is collected by the American Community Survey but was available only for counties that had enough population for data to be published in three-year summaries, instead of five-year summaries, which were used in this assessment.

Additional data limitations could be overcome with more time and expertise. For example, future assessment updates could include landscape level features such as percentage of green cover, percentage of impervious surface, or percentage of water bodies by county.

DATA ACCURACY

The vast majority of the population vulnerability data was obtained through the U.S. Census American Community Survey. The data were displayed at county level using five-year averages of estimates. The sample size is only one in 40 households over the five-year period, versus one in six households from the Decennial Census. The margins of error for this data are very high, but it is the most consistent source of data for these measures.

DATA AGGREGATION AND GEOGRAPHIC DISPLAY

Aggregation of data at the county level provides an important statewide overview, but masks the disparities in sub-county populations and may make counties with small pockets of high vulnerability not stand out. Additionally, county level data limits the usefulness of the analysis for local public health and planners who need to see the distribution of populations within their jurisdiction to develop meaningful plans and interventions. A future project could do a similar analysis at the census tract level to assess how much information is lost from moving from high spatial resolution (census tract) to low spatial resolution (county).

VALIDATION OF METHODOLOGY

How an individual measure is defined, such as the number of extreme heat declarations or the number of flash flood events, requires assumptions that cannot be teased out in the vulnerability assessment. For example, does the definition(s) used by the National Weather Service stations for heat event declarations provide a meaningful threshold for heat exposure risk? How does an event lasting two days compare to an event lasting 15 days? What about using a metric like number of days above the 95th percentile? Similar questions arise for flash flood events. The definition implies that six inches or more of rain falling in a 24-hour time period has significant meaning for infrastructure damage and human health impacts when used in a vulnerability assessment. More research is needed to determine whether these thresholds and definitions are meaningful for communities in Minnesota.

Additionally, the methodology used in the composite vulnerability scores for heat, air pollution and flash floods is not necessarily the most accurate or effective method of measuring vulnerability. While it is important to use a simple additive measure because it can be easily replicated, this process assumes that the percentage of children has the same effect on heat vulnerability as the percentage of persons in poverty. Future updates to the vulnerability assessment may include trying different weighting schemes to understand the importance of each variable in predicting vulnerability. Other future projects could include validation of the measures of vulnerability. For example, one could compare the heat vulnerability analysis to actual incidence of heat-related illness and deaths as collected by 911 calls, emergency department visits, and death records.

Next steps

The next requirement of the BRACE CDC funding is to conduct climate vulnerability assessments at finer geographic levels to help public health departments and others plan for the impacts of climate change. MDH is interested in working with local communities to conduct climate vulnerability assessments, ideally at the county or city geography.

Additionally, MDH plans to visit all eight State Community Health Services Advisory Committee (SCHSAC) Regions to share this document with local communities and learn about their efforts to adapt to climate change. The regional discussions will hopefully identify actions local public health, emergency managers, and planners can take to reduce risk or strategies to assist vulnerable populations before, during and after extreme weather events or hazards. This climate change vulnerability assessment helps lay the groundwork for meaningful dialogue and action on preparing Minnesota communities for the public health impacts of climate change.

Conclusion

Extreme heat, heavy downpours, flooding, drought, vector-borne diseases, and poor air quality have affected and will continue to affect Minnesotans. Many of these hazards are expected to increase, occurring more often and with greater magnitude in the future due to climate change. These "climate hazards" present major challenges to the health and quality of life of Minnesotans. This report advances our understanding of several of these climate hazards and the populations that are most vulnerable to the hazards. With this information, state and local government, companies, institutions and community organizations can begin important discussions about the risks of climate change to their communities, how best to prepare for them, and how to protect everyone, including the most vulnerable, to ensure a healthy and prosperous state.

XI Appendix A:

Final literature review of populations vulnerable to natural hazards and climate change and vulnerability assessments

Study	Climate Change Impacts	Vulnerable Populations	Geography
Balbus JM, Malina C. 2009. Identifying Vulnerable Subpopulations for Climate Change Health Effects in the United States. Journal of Occupational & Environmental Medicine 51:33-37. COI: 10.1097/JOM.0b013e318193e12e	Heat stress, air pollution health effects, extreme weather event health effects, water-, food-, and vector-borne illnesses	Children, pregnant women, older adults, impoverished populations, people with chronic conditions and mobility and cognitive constraints, outdoor workers, and those in coastal and low-lying riverine zones	N/A
Wisner B, Blaikie P, Cannon T, Davis I. 2003. At Risk (Second Edition): Natural Hazards, People's Vulnerability and Disasters. Copyright Wisner, Blaikie, Cannon and Davis.	Hazards affecting human activities (e.g., floods, drought, earthquakes, hurricanes, volcanic eruptions, diseases, etc.)	Class – gender – ethnicity – age group – disability – immigration status, etc.	N/A
California Environmental Public Health Tracking Program. ASTHO Climate change population vulnerability screening tool. California Department of Public Health.	Extreme heat events, flooding, wildfires	Air conditioning ownership, impervious surface and tree canopy, transportation access (public transit and personal vehicle), elderly living alone, environmental justice vulnerability measure (see Sadd et al, 2011)	Census Tract
Climate Change Public Health Impacts Assessment and Response Collaborative. 2007. Public Health Impacts of Climate Change in California: Community Vulnerability Assessment and Adaptation Strategies Report No. 1: Heat-Related Illness and Mortality Information for the Public Health Network in California. California Department of Public Health and the Public Health Institute	Heat (Change in average temperature 1950-2000; heat islands – impervious surface; average daily maximum temperature in July 2006 – heat wave; departures from average maximum and minimum temperatures in July 2006; geographic distribution of deaths due to heat July 2006; Also: elevation and ozone)	Air conditioner ownership; elderly (65+); children (< 5); participants in athletic events; outdoor workers; medically compromised (existing medical conditions and use of certain medications and/or alcohol) and socially isolated (65+ living alone and 65+ living in a nursing home); poverty	Data presented statewide (CA) at the county level

Study	Climate Change Impacts	Vulnerable Populations	Geography
Cutter S, Boruff B, Lynn Shirley W. 2003. Social Vulnerability to Environmental Hazards. Social Science Quarterly, Vol 84, Num 2, June 2003.	N/A (general social vulnerability index to express vulnerability to all hazards, unrelated to climate change)	Socioeconomic status, gender, race and ethnicity, age, commercial and industrial development, employment loss, ruran/ urban, mobile homes, infrastructure, renters, occupation, family structure (size, single parent, etc.), educational attainment, rate of population growth, density of medical services, social dependence, and special needs populations	County
Ebi K, Berry P, Campbell-Lendrum D, Corvalan C, Guillemot J. Protecting Health from Climate Change: Vulnerability and Adaptation Assessment. World Health Organization.	Extreme heat, air pollution, extreme weather events, vector-borne diseases, waterborne/ foodborne diseases	Infants and children, pregnant women, elderly people and people with chronic medical conditions, impoverished/low socioeconomic status, and outdoor workers	N/A
English P, et al. 2009. Environmental health indicators of climate change. Environmental health perspectives. Vol 117; Num 11. Preparedness Study. City of Flagstaff.	Environmental indicators: Greenhouse Gas Emissions, air stagnation events, temperatures, heat index, heat alerts/warnings, wildfires, drought, harmful algal blooms; Morbidity and Mortality indicators: morbidity and mortality to extreme heat, injuries and mortality from extreme weather events; vector-borne disease, respiratory and allergic disease (could also be an indicator of vulnerability indicating pre-existing health condition) days, more heat waves, increased forest fires, greater water challenges); changes to precipitation patterns (greater water challenges, increased flooding events); reduced snowpack and streamflow (greater water challenges, loss in winter recreation)	Elderly living alone, poverty status, children, infants, individuals with disabilitiescould be impacted by changes in climate; primary systems included emergency services, energy, forest health, public health, stormwater, transportation and water)	Not mapped; data listed is available at a variety of geographic levels were not utilized)

Study	Climate Change Impacts	Vulnerable Populations	Geography
Houghton A et al. 2012. Climate change-related vulnerabilities and local environmental public health tracking through GEMSS: A web-based visualization tool. Applied Geography 33:36-44.	Extreme heat and heavy rainfall-induced flooding, 100-year flood plain, low water crossing, impervious surface/ lack of vegetative cover, surface temperature	Pre-existing chronic disease (baseline cardiovascular mortality as a proxy measure of vulnerability to extreme heat, diabetes and hypertension mortality as a proxy measure for potential medical displacement during flooding), age, ethnicity, social isolation, population density	Data presented for Austin, Travis County, TX at the Census Block Group level
Keim M. 2006. A Concept Paper for Mapping Public Health Hazard Vulnerability in the U.S. Centers for Disease Control and Prevention NCEH/ATSDR.	N/A (general social vulnerability index to express vulnerability to all hazards, unrelated to climate change)	Public health vulnerability assessments (age 65 and over, age 15 and younger, female, income, child poverty, academic achievement, English proficiency, death rate, maternal mortality, hospital bed availability)	Lowest level available by data source
Keim M. 2007. CDC/ATSDR Public Health Vulnerability Mapping System: Using A Geographic Information System for Depicting Human Vulnerability to Environmental Emergencies. Centers for Disease Control and Prevention NCEH/ATSDR.	N/A, unrelated to climate change. General Hazards: natural (thunderstorms, tornadoes, earthquakes, floods, hurricanes, blizzards, wild fires, heat waves, volcanic eruptions, mudslides/ landslides), technological (anthropogenic), acts of terrorism, hazardous materials and hazardous waste transportation	Age, racial and ethnic disparities, occupation, personal wealth, housing stock and tenancy, density of the built environment, single-sector dependence, infrastructure dependence, and persons with disabilities; also location of population by time of day (residences, businesses, commute, schools, temporary populations, and shopping centers, sports arenas and other venues of potential interest)	County
Morrow BH. 1999. Identifying and	N/A (general social vulnerability index	Residents of group living facilities;	N/A
Mapping Community Vulnerability, Disasters, 23(1):1-18.	to express vulnerability to all hazards, unrelated to climate change)	elderly, particularly frail elderly; physically or mentally disabled; renters; poor households; women-headed households; ethnic minorities (by language); recent residents/ immigrants/ migrants; large households; large concentrations of children/youth; the homeless; and tourists and transients.	

Study	Climate Change Impacts	Vulnerable Populations	Geography
Moser S, Ekstrom J. 2010. Developing Adaptation Strategies for San Luis Obispo County: Preliminary Climate Change Vulnerability Assessment for Social Systems. Prepared for the Local Government Commission and the San Luis Obispo Stakeholder Workshop on May 20, 2010.	Heat, floods, air pollution	Floodplain residents, outdoor workers, infants, elderly, institutionalized populations (e.g., persons with mental disabilities, prisoners), socially exc-luded and economically marginalized groups, economic sectors, community services	Census Tract
Reid C, O'Neill M, Gronlund C, Brines S, Brown D, Diez-Roux A, Schwartz J. 2009. Mapping Community Determinants of Heat Vulnerability. Health Perspect 117:1730–1736. doi:10.1289/ehp.0900683	Heat	Age, poverty, education, living alone, and race/ethnicity; land cover; diabetes prevalence; air conditioning	Census Tract (socio-economic variables and land cover), county (diabetes and air conditioning)

Study	Climate Change Impacts	Vulnerable Populations	Geography
Sadd et al. 2011. Playing It Safe: Assessing cumulative impact and social vulnerability through an environmental justice screening method in the south coast air basin, California. Int. J. Environ. Res. Public Health, 8, 1441-1459; doi:10.3390/ijerph8051441	N/A	Sensitive Land Uses (childcare facilities, healthcare facilities, schools, urban play-grounds); Environmental Hazards (Facilities in California Community Health Air Pollution Information System (CHAPIS), chrome platers, hazardous waste sites, hazardous land uses, railroad facilities, ports, airports, refineries, intermodal distribution, Risk Screening Environ-mental Indicators (RSEI) toxic concentration hazard score, National Air Toxics Assessment respiratory hazard for air toxics from mobile and stationary emissions, Estimated cancer risks from modeled ambient air toxics concentrations from mobile and stationary emissions, PM2.5 and ozone estimated concentration interpolated from CARB's monitoring data); and Social Vulnerability Indicators (% people of color, % below twice the national poverty level, % living in rented house-holds, median housing value, educational attainment, age, linguistic isolation, voter turnout, and birth outcomes)	Census Tract

XII Appendix B

Master list of indicators (prior to culling)

Map	Topic	Subtopic	Available Data Source(s)	Citation
Stagnation air mass events	Climate hazard	Air Quality	See the http://www.cste.org/?page=EHIndicatorsClimate, Environmental Indicator #2	9
Ozone estimates (due to climate change)	Climate hazard	Air Quality	Minnesota Department of Health, Minnesota Public Health Data Access, Air Quality (https://apps.health.state.mn.us/mndata/air_query)	9
Pollen counts, ragweed presence	Climate hazard	Air Quality	Minneapolis Pollen Counter, http://www.cste.org/?page=EHIndicatorsClimate Environmental Indicator #4	9
Respiratory/allergic disease and mortality related to increased air pollution and pollens	Climate hazard	Air Quality	Minnesota Department of Health, Minnesota Public Health Data Access (https://apps.health.state.mn.us/mndata/home): Asthma, COPD	9
Droughts: Palmer Drought Severity Index	Climate hazard	Drought	NOAA National Climatic Data Center Historical Palmer Drought Indices (http://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers.php)	9
100-year flood plain	Climate hazard	Flood	DNR Data Deli (http://deli.dnr.state.mn.us/data_catalog.html): FEMA Floodplain	11
Low water crossing	Climate hazard	Flood	Possibly USGS or local watershed organization	11
Change in Average Temperature	Climate hazard	Heat	DNR Data Deli: Minnesota Temperature Average (1961-1990) http://deli.dnr.state.mn.us/metadata.html?id=L290000020201	16
Location of heat warnings	Climate hazard	Heat	NOAA National Climatic Data Center, Storm Events Database (http://www.ncdc.noaa.gov/stormevents/)	9
Excess mortality due to extreme heat	Climate hazard	Heat	Minnesota Department of Health Minnesota Public Health Data Access, Heat-Related Illness (https://apps.health.state.mn.us/mndata/heat)	9
Excess morbidity due to extreme heat	Climate hazard	Heat	Minnesota Department of Health Minnesota Public Health Data Access, Heat-Related Illness (https://apps.health.state.mn.us/mndata/heat)	9

Map	Topic	Subtopic	Available Data Source(s)	Citation
Intersection of Elevation, Increased Temperatures, and Ozone levels	Climate Hazard	Heat/Air Quality		16
Impervious Surfaces	Climate Hazard	Heat/ Flood	DNR Data Deli: Imperviousness (http://deli.dnr.state.mn.us/metadata.html?id=L390006060606)	11, 16
Tree canopy	Climate Hazard	Heat/ Flood	Minneapolis Urban Tree Canopy, St. Paul Trees (http://www.minneapolismn.gov/sustainability/action/canopy/sustainability_mplsurbantreecanopymap)	3
Human cases of environmental infectious disease/positive test results in reservoirs/sentinels/vectors	Climate Hazard	Infectious disease	Minnesota Department of Health, Vector-borne diseases (http://www.health.state.mn.us/divs/idepc/dtopics/vectorborne/)	9
Number of injuries/mortality from extreme weather events (Excess ER visits and hospitalizations (Heat stroke/CLRD) over established baseline)	Climate Hazard	Multiple Hazards	See http://www.cste.org/?page=EHIndicatorsClimate	9
Harmful algal blooms (outbreaks)	Climate Hazard	Water Quality		9
Frequency, severity, distribution, and duration of wildfires	Climate Hazard	Wildfire	NOAA National Climatic Data Center, Storm Events Database (http://www.ncdc.noaa.gov/stormevents/)	9
Physical and mental disabilities	Health Risk		U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	9, 12, 14, 17
Disabilities: % older than 5 with a disability	Health Risk		U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	4, 6, 15
Hearing impaired	Health Risk		U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	13
Pregnant women	Health Risk			1
Chronic medical conditions	Health Risk		CDC Behavioral Risk Factor Surveillance Survey (http://apps.nccd.cdc.gov/brfss/index.asp)	17
Diabetes and hypertension mortality as a proxy measure for potential medical displacement during flooding	Health Risk		CDC Behavioral Risk Factor Surveillance Survey (http://apps.nccd.cdc.gov/brfss/index.asp)	11
Dialysis patients	Health Risk			
Medication: Number of people taking beta blocking medications	Health Risk			1
Prior hospitalization	Health Risk			6

Map	Topic	Subtopic	Available Data Source(s)	Citation
Crude death rate	Health Risk		MDH Vital Statistics (http://www.health.state.mn.us/divs/chs/)	5
Baseline cardiovascular mortality - proxy measure of vulnerability to extreme heat	Health Risk		Minnesota Department of Health, Minnesota Public Health Data Access, Heart Attacks (https://apps.health.state.mn.us/mndata/mci)	11
Maternal mortality ratio (per 100,000 live births)			MDH Vital Statistics (http://www.health.state.mn.us/divs/chs/)	5
Medication: Number of people taking beta blocking medications	Health Risk			1
Prior hospitalization	Health Risk			6
Crude death rate	Health Risk		MDH Vital Statistics (http://www.health.state.mn.us/divs/chs/)	5
Baseline cardiovascular mortality - proxy measure of vulnerability to extreme heat	Health Risk		Minnesota Department of Health, Minnesota Public Health Data Access, Heart Attacks (https://apps.health.state.mn.us/mndata/mci)	11
Maternal mortality ratio (per 100,000 live births)			MDH Vital Statistics (http://www.health.state.mn.us/divs/chs/)	5
Physicians per 1,000 population	Health Risk		Census Table B–4. Counties - Vital Statistics and Health (http://www.census.gov/prod/2002pubs/00ccdb/cc00_tabB4.pdf)	5
Hospital beds per 10,000 population	Health Risk		Census Table B–4. Counties - Vital Statistics and Health (http://www.census.gov/prod/2002pubs/00ccdb/cc00_tabB4.pdf)	5
Access to personal transportation (households with car)	Population vulnerability	Access	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	
Transit Access: No. within walking distance of public transit	Population vulnerability	Access	Census, or parcel data	15
Schools/child care facilities (sensitive land uses)	Population vulnerability	Age	Parcel data, or Minnesota Department of Human Services Licensing Information Lookup, or Minnesota Department of Education (http://licensinglookup.dhs.state.mn.us/)	18
Large household size	Population vulnerability	Density	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	14, 17

Map	Topic	Subtopic	Available Data Source(s)	Citation
Large concentrations of children	Population vulnerability	Density	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	14
Households eligible for energy assistance	Population vulnerability	Economic	Minnesota Department of Commerce (https://mn.gov/commerce/energy/topics/financial/Energy-Assistance-Program/Eligibility-Guidelines.jsp)	16
Medicaid	Population vulnerability	Economic	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	7
Unemployment: % civilians unemployed	Population vulnerability	Economic	Minnesota Department of Employment and Economic Development, Local Area Unemployment Statistics (LAUS), (http://mn.gov/deed/data/data-tools/laus.jsp) or U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	10
Socio-economic status	Population vulnerability	Economic	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	2
Per capita income	Population vulnerability	Economic	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	5
Per capita income (personal wealth) also, median income, poverty, housing value	Population vulnerability	Economic	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	4
Child poverty rate	Population vulnerability	Economic	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	5
% Families with children below poverty level	Population vulnerability	Economic	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	5
Population reliant on Social Security	Population vulnerability	Economic	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	4
Occupation (low paying jobs w/ few or no benefits; unemployed; sectors that could be affected by hazard; dominant industry) -- per capita income and poverty as proxy too	Population vulnerability	Economic	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	4
Type of employment/Occupation: % outdoor labors	Population vulnerability	Social	Minnesota Department of Employment and Economic Development, Quarterly Census of Employment and Wages (http://mn.gov/deed/data/data-tools/laus.jsp), or U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	1, 17
Population 65 and Older living in a nursing home	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	16

Map	Topic	Subtopic	Available Data Source(s)	Citation
Single-headed households with children under 18	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	15
Women-headed households	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	14
Renters	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	14
Homeless	Population vulnerability	Social	Wilder Research, Statewide Homeless Study (http://www.wilder.org/Wilder-Research/Research-Areas/Homelessness/Pages/statewide-homeless-study-most-recent-results.aspx)	14
Recent residents/immigrants	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	14
Tourists and transient populations	Population vulnerability	Social		14
Race	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	17
Ethnicity	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	2, 11, 14, 17
Race & Ethnicity (esp. African American, Hispanic/Latino, and Asian)	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	4, 15
National origin	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	2
% Households that use language other than English as primary language/Limited English speaking population	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	4, 5, 15
Education: Below HS degree	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	15
Number of persons (either age 18+ or age 25+) without a high school degree	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	5
Age	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	2, 6, 8, 11
% Population under 15 years old	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	5
Population 17 years and younger	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	4, 15

Map	Topic	Subtopic	Available Data Source(s)	Citation
Socio-economic class	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	2
Gender	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	2, 6
% Population female	Population vulnerability	Social	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	5
Socially isolated	Population vulnerability	Social		11
Population density	Built environment risk	Density	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	11
Population growth: Growth rate	Built environment risk	Density	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	15
Density of the built environment (units/acre or sq mi; # new housing permits)	Built environment risk	Density	Parcel data	4, 15
Density of parcels used for parking	Built environment risk	Density	Parcel data	15
Housing density	Built environment risk	Density	Parcel data, or U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	15
High-rise buildings	Built environment risk	Density	Parcel data	
Housing (stock and tenancy) (e.g., mobile homes, multiple unit structures, old stock; renters; urban residents)	Built environment risk	Durability	U.S. Census Bureau – American Community Survey, FactFinder (http://factfinder2.census.gov/)	4, 8, 15
Single-sector dependence (% employed in extractive industries -- fishing, farming and mining; and % classified as rural farm)	Built environment risk	Economic		5

Map	Topic	Subtopic	Available Data Source(s)	Citation
Infrastructure dependence (1) large debt-to-revenue ratio for counties and 2) percent of workers employed in public utilities, transportation and communication)	Built environment risk	Economic		5
GHG emissions	Mitigation - Response		Minnesota Pollution Control Agency – Greenhouse gas emissions (http://www.pca.state.mn.us/index.php/topics/climate-change/climate-change-in-minnesota/report-on-greenhouse-gas-emissions-in-minnesota.html)	9
Energy efficiencies	Mitigation - Response		Minnesota Department of Commerce –Efficiency (http://mn.gov/commerce/energy/topics/efficiency/)	9
Use of renewable energy	Mitigation - Response		Minnesota Department of Commerce – Clean Energy (http://mn.gov/commerce/energy/topics/clean-energy/)	9
Number of vehicle miles traveled	Mitigation - Response		Minnesota Department of Transportation – Roadway Data (http://www.dot.state.mn.us/roadway/data/)	9
Access to cooling centers	Mitigation - Response			9
Number of heat wave warning systems	Mitigation - Response			9
Number of municipal heat island mitigation plans	Mitigation - Response			9
Number of health surveillance systems related to climate change	Mitigation - Response			9
Public health workforce available/trained in climate change research/surveillance/adaptation	Mitigation - Response			9
Number of cities/municipalities covered by Kyoto protocol	Mitigation - Response		US Conference of Mayors Climate Protection Center (http://www.usmayors.org/climateprotection/revised/)	9
Number of states/cities participating in climate change activities	Mitigation - Response		See http://www.cste.org/?page=EHIndicatorsClimate	9
Number and location of community centers	Mitigation - Response			9
Number of weather response education programs completed	Mitigation - Response			9

Table Citations

(1) Balbus JM, Malina C. 2009. Identifying Vulnerable Subpopulations for Climate Change Health Effects in the United States. Journal of Occupational & Environmental Medicine 51:33-37. COI: 10.1097/JOM.0b013e318193e12e

(2) Bolin R, Stanford L. 1998. The Northridge Earthquake: Community-based Approaches to Unmet Recovery Needs. Disasters. 22(1):21-38

(3) California Environmental Health Tracking Program (CEHTP). 2012. ASTHO Climate change population vulnerability screening tool. Sacramento, CA: California Department of Public Health.

(4) Keim el at. 2007. CDC/ATSDR Public Health Vulnerability Mapping System: Using A Geographic Information System for Depicting Human Vulnerability to Environmental Emergencies. NCEH Office of Terrorism Preparedness and Emergency Response and ATSDR Geospatial Research Analysis and Services Program.

(5) Keim M. 2006. A Concept Paper for Mapping Public Health Hazard Vulnerability in the U.S. NCEH/ATSDR Office for Terrorism Preparedness and Response. Centers for Disease Control and Prevention.

(6) Chou YJ, Huang N, Lee CH, Tsai SL, Chen LS, Chang HJ. 2004. Who is at Risk of Death in an Earthquake? Am J Epidemiol. Oct 1;160(7):688-95

(7) Domino ME, Fried B, Moon Y, Olinik J, Yoon J. 2003. Disasters and the Public Health Safety Net: Hurricane Floyd Hits the North Carolina Medicaid program. Am J Public Health. 93: 1122-1127

(8) Edison M, Alybarger J, Parsons JE, Maccormack JN, Freeman JI. 1990. Risk Factors for Tornado Injuries. Int. J. Epidemiol. 19: 1051-1056

(9) English P, et al. 2009. Environmental health indicators of climate change. Environmental health perspectives. Vol 117; Num 11.

(10) Geospatial Research A., and Services Program. 2008. Ramsey County Human Vulnerability Assessment, in: A.f.T.S.D. Registry (Ed.).

(11) Houghton A et al. 2012. Climate change-related vulnerabilities and local environmental public health tracking through GEMSS: A web-based visualization tool. Applied Geography 33:36-44.

(12) Kaiser R, et al. 2004. Air Pollution Attributable Post-neonatal Infant Mortality in U.S. Metropolitan Areas: A Risk Assessment Study. J Environmental Health: A Global Access Science Source 3.

(13) Minnesota Department of Health Office of Emergency Preparedness. 2011. County Emergency Response Capabilities list (internal document)

(14) Morrow BH. 1999. Identifying and Mapping Community Vulnerability. Disasters. 23(1):1-18

(15) O'Neill ME. 2009. Temperature Extremes and Health: Impacts of Climate Variability and Change in the United States. Journal of Occupational Environmental Medicine 51:13-25.

(16) California Department of Public Health and the Public Health Institute. 2007. Public Health Impacts of Climate Change in California: Community Vulnerability Assessment and Adaptation Strategies. Available at: http://www.ehib.org/papers/Heat_Vulnerability_2007.pdf

(17) Rapid Assessment of Health Needs and Resettlement Plans among Hurricane Katrina Evacuees -- San Antonio, Texas, September 2005. Available at: http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5509a6.htm

(18) Sadd et al. 2011. Playing It Safe: Assessing cumulative impact and social vulnerability through an environmental justice screening method in the south coast air basin, California. Int. J. Environ. Res. Public Health, 8, 1441-1459; doi:10.3390/ijerph8051441

XIII References

Akbari, H. 2005. Energy Saving Potentials and Air Quality Benefits of Urban Heat Island Mitigation. Lawrence Berkeley National Laboratory.

Amann, Swart, Raes, Tuinstra. 2004. A good climate for clean air: linkages between climate change and air pollution. Climatic Change 66: 263–269; Bernard SM, Samet JM, Grambsch A, Ebi KL, Romieu I. 2001. The potential impacts of climate variability and change on air pollution-related health effects in the United States. Environmental Health Perspectives Vol 109, Supplement 2, pp 199-209; Jacob DJ, Winner DA. 2009. Effect of climate change on air quality. Atmospheric Environment, Vol 34, pp. 51-63.

American Lung Association. 2012. State of the Air 2012. http://www.stateoftheair.org/2012/assets/state-of-the-air2012.pdf

American Medical Association Council on Scientific Affairs. 1997. Heat-Related Illness During Extreme Weather Emergencies. Report 10 of the Council on Scientific Affairs (A-97). Presented at the 1997 AMA Annual Meeting.

Baccini M, Biggeri A, Accetta G, Kosatsky T, Katsouyanni, K, et al. 2008. Heat effects on mortality in 15 European cities. Epidemiology, 19 (5), 711.

Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., 2008: Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.

Bennett, T. M. B., N. G. Maynard, P. Cochran, R. Gough, K. Lynn, J. Maldonado, G. Voggesser, S. Wotkyns, and K. Cozzetto, 2014: Ch. 12: Indigenous Peoples, Lands, and Resources. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 297-317. doi:10.7930/J09G5JR1.

Bernard SM, Samet JM, Grambsch A, Ebi KL, Romieu I. 2001. The potential impacts of climate variability and change on air pollution-related health effects in the United States. Environmental Health Perspectives Vol 109, Supplement 2, pp 199-209.

Bouchama A, Knochel JP. 2002. Heat stroke. N Engl J Med;346:1978–88.

Brown, P., B. Mayer, S. Zavestoski, T. Luebke, J. Mandelbaum, and S. McCormick. 2003. The health politics of asthma: Environmental justice and collective illness experience in the United States. Social Science and Medicine 57: 453-464.

Burt B. 2001. Definitions of Risk. University of Michigan, School of Public Health, Department of Epidemiology.

Bytomski JR, Squire DL. 2003. Heat illness in children. Curr Sports Med Rep.;2(6):320-4.

CCSP (U.S. Climate Change Science Program). 2008. Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems: Final Report, Synthesis and Assessment Product 4.6. Washington, DC: U.S. Environmental Protection Agency.

Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner, 2013: Long-term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Congressional Black Caucus Foundation, Inc. 2004. African Americans and Climate Change: An Unequal Burden. Available online: http://rprogress.org/publications/2004/CBCF_REPORT_F.pdf

Crouse DL, Peters PA, van Donkelaar A, Goldberg MS, Villeneuve PJ, Brion O, Khan S, Atari DO, Jerrett M, Pope III CA, Brauer M, Brook JR, Martin RV, Stieb D, Burnett RT. Risk of Non-accidental and Cardiovascular Mortality in Relation to Longterm Exposure to Low Concentrations of Fine Particulate Matter: A Canadian National-level Cohort Study. Environ Health Perspect 2012. Available In-Press online 7 February 2012. http://dx.doi.org/10.1289/ehp.1104049.

Curriero FC, Heiner KS, Samet JM, Zeger SL, Strug L, Patz JA. 2002. Temperature and mortality in 11 cities of the eastern United States. Am J Epidemiol.;155(1):80-7.

Cutter SL, Boruff BJ, Shirley WL. Social vulnerability to environmental hazards. Soc Sci Q. 2003;84(2):242---261.

Dales R, Chen L, Frescura AM, Liu L, Villeneuve PJ. Acute effects of outdoor air pollution on forced expiratory volume in 1 s: a panel study of schoolchildren with asthma. Eur Respir J 2009; 34:316-323.

English P, et al. 2009. Environmental health indicators of climate change. Environmental health perspectives. Vol 117; Num 11.

Federal Emergency Management Agency (FEMA). 2013a. Flood or Flooding. Available at http://www.fema.gov/floodplain-management/flood-or-flooding

Federal Emergency Management Agency (FEMA). 2013b. Policy Rates. Available at http://www.floodsmart.gov/floodsmart/pages/residential_coverage/policy_rates.jsp

Federal Emergency Management Agency (FEMA). 2013c. Community Status Book: Minnesota. Accessed 7/9/2013. Available at http://www.fema.gov/national-flood-insurance-program/national-flood-insurance-program-community-status-book

Fletcher BA, Lin S, Fitzgerald EF, Hwang SA. 2012. Association of summer temperatures with hospital admissions for renal diseases in New York State: A case-crossover study. Am J Epidemiol 175:907-916.

Foster, K. G., Ellis, F. P., Dore, C. et al. 1976. Sweat Responses in the Aged. Age and Ageing, 5, 91-101.

Gage, K. L., T. R. Burkot, R. J. Eisen, and E. B. Hayes, 2008: Climate and vectorborne diseases. American Journal of Preventive Medicine, 35, 436-450, doi:10.1016/j.amepre.2008.08.030.

Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press, 2009.

Governor Dayton, M. 2012. Individual Assistance request to President Barak Obama. July 19, 2012.

Green H, Gilbert J, James R, and Byard, RW. 2001. An analysis of factors contributing to a series of deaths caused by exposure to high environmental temperatures. The American Journal of Forensic Medicine and Pathology, 22(2), 196.

Hajat S, Kovats RS, Lachowycz K. 2007. Heat-related and cold-related deaths in England and Wales: who is at risk? Occup Environ Med.;64(2):93-100.

Horstmeyer, SL. 2008. Relative humidity . . . Relative to what? The dew point temperature: a better approach. Available online: http://www.shorstmeyer.com/wxfaqs/humidity/humidity.html

Hotez, P. 2008. Neglected Infections of Poverty in the United States of America. PLoS Negl Trop Dis 2(6). DOI: 10.1371/journal.pntd.0000256.

Hristov AN. 2011. Technical note: Contribution of ammonia emitted from livestock to atmospheric fine particulate matter (PM2.5) in the United States. J Dairy Sci. 2011 Jun;94(6):3130-6.

Huttner P. 2012. Colorado wildfire smoke in MN. MPR News: Updraft. Available at http://blogs.mprnews.org/updraft/2012/06/colorado_wildfire_smoke_in_mn/

Islam T, McConnell R, Gauderman WJ, Avol E, Peters JM, and Gilliland F, Ozone, oxidant defense genes, and risk of asthma during adolescence. Am J Respir Crit Care Med 2009; 177(4):388-395.

Jacob DJ, Winner DA. 2009. Effect of climate change on air quality. Atmospheric Environment ,Vol 34, pp. 51-63.

Kaiser R, Le Tertre A, Schwartz J, Gotway CA, Daley WR, and Rubin CH. 2007. The effect of the 1995 heat wave in Chicago on all-cause and cause-specific mortlaity. American Journal of Public Health, 97(Supplement 1), S158.

Kalkstein, L. 1992. Impacts of global warming on human health: Heat stress-related mortality. In, Global Climate Change: Implications, Challenges and Mitigation Measures, eds. S. Majumdar, L. Kalkstein, B. Yarnal, E. Miller and L. Rosenfield. Easton, PA; Pennsylvania Academy of Science.

Keim M. 2006. A Concept Paper for Mapping Public Health Hazard Vulnerability in the U.S. Centers for Disease Control and Prevention NCEH/ATSDR.

Keim M. 2007. CDC/ATSDR Public Health Vulnerability Mapping System: Using A Geographic Information System for Depicting Human Vulnerability to Environmental Emergencies. Centers for Disease Control and Prevention NCEH/ATSDR.

Knowlton K, Rotkin-Ellman M, King G, Margolis HG, Smith D, and Solomon G, et al. 2009. The 2006 California heat wave: impacts on hospitalizations and emergency department visits. Environ Health Perspect 117:61-67.

Lee et al. 2013. Hunter killed deer surveillance to assess changes in the prevalence and distribution of Ixodes scapularis in Wisconsin.Journal of Medical Entomology 50: 632-639.

Lin S, Luo M, Walker RJ, Liu X, Hwang SA, Chinery R. 2009. Extreme high temperatures and hospital admissions for respiratory and cardiovascular diseases. Epidemiology 20:738-746.

Lin S. 2008. Understanding Climate Change: An Equitable Framework. Policy Link.

Lopez, R. 2002. Segregation and Black/White differences to exposure to air toxics in 1990. Environmental Health Perspectives 110(S2): 289-295.

Luber, G., K. Knowlton, J. Balbus, H. Frumkin, M. Hayden, J. Hess, M. McGeehin, N. Sheats, L. Backer, C. B. Beard, K. L. Ebi, E. Maibach, R. S. Ostfeld, C. Wiedinmyer, E. Zielinski-Gutiérrez, and L. Ziska, 2014: Ch. 9: Human Health. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 220-256. doi:10.7930/J0PN93H5.

Luber, G., K. Knowlton, J. Balbus, H. Frumkin, M. Hayden, J. Hess, M. McGeehin, N. Sheats, L. Backer, C. B. Beard, K. L. Ebi, E. Maibach, R. S. Ostfeld, C. Wiedinmyer, E. Zielinski-Gutiérrez, and L. Ziska, 2014: Ch. 9: Human Health. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 220-256. doi:10.7930/J0PN93H5.

Mannino, D., D. Homa, L. Akinbami, J. Moorman, C. Gwynn, and S. Redd. 2002. Surveillance for asthma—United States: 1980-1999. CDC Morbidity and Mortality Weekly Report 51(SS-1): 1-16.

Mays VM, Cochran SD, Barnes NW. Race, race-based discrimination, and health outcomes among African Americans. Annu. Rev. Psychol., 2007 - annualreviews.org

McConnell R, Berhane K, Gilliland F, et al. Asthma in exercising children exposed to ozone: a cohort study. Lancet. 2002;359:386 –391.

McGeehin, M. and M. Mirabelli. 2001. The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. Environmental Health Perspectives 109(S2): 185-189.

Medina-Ramon M, Zanobetti A, Schwartz J. The effect of ozone and PM10 on hospital admissions for pneumonia and chronic obstructive pulmonary disease: a national multicity study. Am J Epidemiol 2006; 163:579-588.

Midwestern Regional Climate Center (MRCC). 2011. Climate Change and Variability in the Midwest: Temperature Trends 1895-2010. Accessed August 8, 2013. Available online: http://mrcc.isws.illinois.edu/climate_midwest/mwclimate_change.htm

Minnesota Climatology Working Group (MCWG). 2012a. Minnesota Flash Floods: 1970-2012. Accessed 7/10/2013. Available at http://www.dnr.state.mn.us/climate/summaries_and_publications/flash_floods.html

Minnesota Climatology Working Group (MCWG). 2012b. Historic Mega-Rain Events in Minnesota. Accessed 8/7/2013. Available at http://www.dnr.state.mn.us/climate/summaries_and_publications/flash_floods.html

Minnesota Department of Health (MDH). 2012. MDH News Release: Private well owners urged to have their water tested.Available at http://content.govdelivery.com/accounts/MNMDH/bulletins/332384

Minnesota Department of Health (MDH). 2013a. Vector-Borne Diseases and Climate Change. Available at http://www.health.state.mn.us/divs/idepc/dtopics/vectorborne/climate.html

Minnesota Department of Health (MDH). 2013b. Lyme Disease Basics. Available at http://www.health.state.mn.us/divs/idepc/diseases/lyme/basics.html

Minnesota Department of Health (MDH). 2013c. Human Anaplasmosis. Available at http://www.health.state.mn.us/divs/idepc/diseases/anaplasmosis/index.html

Minnesota Department of Health (MDH). 2013d. West Nile Encephalitis Fact Sheet. Available at http://www.health.state.mn.us/divs/idepc/diseases/westnile/wnv.html

Minnesota Department of Health (MDH). 2013e. Lyme Disease Statistics. Available at http://www.health.state.mn.us/divs/idepc/diseases/lyme/statistics.html

Minnesota Department of Health (MDH). 2013f. Preventing Tick-borne Disease. Available at http://www.health.state.mn.us/divs/idepc/dtopics/tickborne/prevention.html

Minnesota Department of Health (MDH). 2013g. West Nile Virus in Minnesota: 2003 Update. Available at http://www.health.state.mn.us/divs/idepc/diseases/westnile/dcn504wnv.html

Minnesota Department of Health (MDH). 2013h. Blacklegged Ticks (Deer Tick, Bear Tick). Available at http://www.health.state.mn.us/divs/idepc/dtopics/tickborne/ticks.html

Minnesota Department of Health (MDH). Center for Health Statistics. 2014a. COPD Deaths by Race/Ethnicity. Available online: https://apps.health.state.mn.us/mndata/copd_hosp#chart5

Minnesota Department of Health (MDH). Center for Health Statistics. 2014b. Incidence of lung & bronchus cancer in Minnesota by race/ethnicity. Available online: https://apps.health.state.mn.us/mndata/cancer_lung#lung_ethnicity

Minnesota Department of Health (MDH). Center for Health Statistics. 2014c. Heart disease mortality in Minnesota by race/ethnicity, 2009-2011. Available online: https://apps.health.state.mn.us/mndata/mci_hosp#chart4

Minnesota Department of Natural Resources (DNR). 1989. Drought 1988. DNR Division of

Waters. Available at http://climate.umn.edu/pdf/drought88.pdf

Minnesota Department of Natural Resources (DNR) Division of Waters. 1995. Water Year Data Summary: 1993 and 1994. Available at http://climate.umn.edu/doc/journal/1993flood.pdf

Minnesota Division of Homeland Security and Emergency Management (HSEM). 2011. Minnesota All-Hazard Mitigation Plan Update. Minnesota Department of Public Safety. St. Paul, MN.

Minnesota Geospatial Information Office (MnGeo). 2013. Hillshade, LiDAR-derived, Minnesota. Available at: http://www.mngeo.state.mn.us/chouse/metadata/lidar_hillshade_mn.html

Minnesota Pollution Control Agency (MPCA). 2011. Blue-green Algae and Harmful Algal Blooms. Available online: http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/lake-water-quality/blue-green-algae-and-harmful-algal-blooms.html

Minnesota Pollution Control Agency (MPCA). 2013. Air Quality Index. Accessed August 7, 2013. Available online http://www.pca.state.mn.us/index.php/air/air-quality-and-pollutants/general-air-quality/air-quality-index/air-quality-about-the-data.html.

Minnesota Public Radio (MPR). 2011. Pagami Creek Fire in BWCA now estimated at 100,000 acres. Available online http://minnesota.publicradio.org/display/web/2011/09/13/pagami-fire-60000-acres-evacuations-underway/

Minnesota Student Survey. 2010. Minnesota Departments of Education, Health, Human Services and Public Safety.

Morrow BH. Identifying and mapping community vulnerability. Disasters. 1999;23(1):1---18.

National Climatic Data Center (NCDC). 2013a. Storm Events Database. National Oceanic and Atmospheric Administration. Accessed April 11, 2013. Available at http://www.ncdc.noaa.gov/stormevents/

National Climatic Data Center (NCDC). 2013b. Definition of Drought. National Oceanic and Atmospheric Administration. Accessed April 29, 2013. Available at http://www.ncdc.noaa.gov/climate-monitoring/dyk/drought-definition

National Climatic Data Center (NCDC). 2014. Climate At A Glance. National Oceanic and Atmospheric Administration. Available at http://www.ncdc.noaa.gov/cag/

National Oceanic and Atmospheric Administration (NOAA). 2007. NWS Directive 10-1605. Available at http://www.ncdc.noaa.gov/stormevents/pd01016005curr.pdf

National Oceanic and Atmospheric Administration (NOAA). 2013a. Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 8, Version 2.0: Midwestern States (Colorado, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Oklahoma, South Dakota, Wisconsin). Available at: http://www.nws.noaa.gov/oh/hdsc/currentpf.htm#PF_documents_by_state

National Oceanic and Atmospheric Administration (NOAA). 2013b. Palmer Drought Severity Index. Drought Information Center. Available at: http://www.cpc.ncep.noaa.gov/products/Drought/

National Weather Service (NWS). 2009. National Weather Service Glossary: Flash Flood. National Oceanic and Atmospheric Administration (NOAA).Available at http://w1.weather.gov/glossary/index.php?letter=f

National Wildlife Federation (NWF). 2010. Extreme Allergies and Global Warming. Available online: www.nwf.org/extremeweather

NHLBI Working Group. 1995. Respiratory Diseases Disproportionately Affecting Minorities. CHEST 108: 1380-92.

O'Neill M, Zanobetti A, Schwartz J. 2003. Modifiers of the Temperature and Mortality Association in Seven US Cities. American Journal of Epidemiology Vol 157, No 12. DOI 10.1093/aje/lowg096.

O'Neill ME. 2009. Temperature Extremes and Health: Impacts of Climate Variabillity and Change in the United States. Journal of Occupational Environmental Medicine 51:13-25.

Parker JD, Akinbami LJ, Woodruff TJ. 2009. Air Pollution and Childhood Respiratory Allergies in the United States. Environ Health Perspect 2009; 117: 140-147

Piesman J, Mather TN, Sinsky RJ, Spielman A. 1987. Duration of tick attachment and Borrelia burgdorferi transmission. J Clin Microbiol. March; 25(3): 557-558.

Platt M and Vicario S. 2010. Heat Illness. In Rosen's Emergency Medicine: Concepts and Clinical Practice, 7th Ed. p1882-3.

Pope CA III, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K and Thurston GD. 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA. Vol. 287 (9): 1132-41

Pope CA III. 2000. Epidemiology of fine particulate air pollution and human health: biologic mechanisms and who's at risk? Environ Health Perspect; 108:Supple 4:713-23.

Pryor, S. C., D. Scavia, C. Downer, M. Gaden, L. Iverson, R. Nordstrom, J. Patz, and G. P. Robertson, 2014: Ch. 18: Midwest. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 418-440. doi:10.7930/J0J1012N.

Rogers, CA, PM Wayne, EA Macklin, et al. 2006. Interaction of the onset of spring and elevated atmospheric CO2 on ragweed pollen production. Environmental Health Perspectives 114: 865-869.

Rowland T. 2008. Thermoregulation during exercise in the heat in children: old concepts revisited. J Appl Physiol.;105(2):718-24.

Schifano P, Cappai G, De Sario M, Michelozzi P, Marino C, Bargagli AM, et al. 2009. Susceptibility to heat wave-related mortality: a follow-up study of a cohort of elderly in Rome. Environ Health; 8:50-.

Seeley M. 2012. Climate Trends and Climate Change in Minnesota: A Review. Minnesota State Climatology Office. Available online: http://climate.umn.edu/seeley/

Seely M. 2013. 2013 Minnesota Environmental Congress – Presentation on Climate. Available at http://climate.umn.edu/seeley/

Semenza JC, Rubin CH, Falter KH, Selanikio JD, Flanders WD, Howe HL, et al. 1996. Heat-related deaths during the July 1995 heat wave in Chicago. N Engl J Med.;335(2):84-90.

Sinha, T., and K. A. Cherkauer. 2010. Impacts of future climate change on soil frost in the midwestern United States, J. Geophys. Res., 115, D08105, doi:10.1029/2009JD012188

St. Martin T. Decade of Disconsolation. Accessed July 15, 2013. Available at http://climate.umn.edu/pdf/Decade_of_disconsolation.pdf

Swartz J. 2005. Who is sensitive to extremes of temperature?: A case-only analysis. Epidemiology, 16(1), 67.

Tager IB, Balmes J, Lurmann F, Ngo L, Alcorn S, and Küenzli N. 2005. Chronic Exposure to Ambient Ozone and Lung Function in Young Adults.Epidemiology 2005; 16:751-759.

Tebaldi C, Adams-Smith D, Heller N. 2012. The Heat Is On: U.S. Temperature Trends. Climate Central. Available at http://www.climatecentral.org/wgts/heat-is-on/HeatIsOnReport.pdf

U.S. Centers for Disease Control and Prevention (CDC). 2006a. Frequently Asked Questions (FAQ) About Extreme Heat. Retreived April 17, 2012, from http://www.bt.cdc.gov/disasters/extremeheat/faq.asp.

U.S. Centers for Disease Control and Prevention (CDC). 2006b. Heat-related deaths—United States, 1999-2003. Morbidity and Mortality Weekly Report,; 55(29), 796-798.

U.S. Centers for Disease Control and Prevention (CDC). 2013a. Lone Star tick a concern, but not for Lyme disease, http://www.cdc.gov/stari/disease/ June 18, 2013

U.S. Centers for Disease Control and Prevention (CDC). 2013b. Ehrlichiosis, June 18, 2013. http://www.cdc.gov/ehrlichiosis/

U.S. Environmental Protection Agency (EPA) Office of Atmospheric Programs, Climate Protection Partnership Division. 2008. Reducing Urban Heat Islands: Compendium of Strategies. Available at http://www.epa.gov/hiri/resources/compendium.htm

U.S. Environmental Protection Agency (EPA). 2003. Ozone: good up high, bad nearby.Office of Air and Radiation. EPA-451/K-03-001. http://www.epa.gov/glo/pdfs/ozonegb.pdf

U.S. Environmental Protection Agency (EPA). 2006. Air Quality Criteria for Ozone and Related Photochemical Oxidants (2006 Final). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-05/004aF-cF, 2006.

U.S. Environmental Protection Agency (EPA). 2013a. Particulate Matter: Basic Information http://www.epa.gov/pm/basic.html

U.S. Environmental Protection Agency (EPA). 2013b. National Ambient Air Quality Standards (NAAQS). http://www.epa.gov/air/criteria.html

U.S. Government Accountability Office (GAO). 2013. Flood Insurance: Participation of Indian Tribes in Federal and Private Programs. GAO-13-226. Available at http://www.gao.gov/products/GAO-13-226

United States Census Bureau. 2011. Poverty Data – Poverty thresholds. Available at http://www.census.gov/hhes/www/poverty/data/threshld/index.html

United States Census Bureau. 2012. Disability – American Community Survey (ACS). Available at http://www.census.gov/people/disability/methodology/acs.html

United States Census Bureau. 2013. Language Use – About Language Use. Available at: http://www.census.gov/hhes/socdemo/language/about/index.html

United States Department of Agriculture (USDA) Global Change Task Force. 2010.USDA Climate Change Science Plan. U.S. Department of Agriculture. Available at http://www.usda.gov/oce/climate_change/science_plan2010/USDA_CCSPlan_120810.pdf

USDA National Agricultural Statistics Service. 2013. Crop Production Down in 2012 Due to Drought, USDA Reports. Available at http://www.nass.usda.gov/Newsroom/2013/01_11_2013.asp

Vandentorren S, Bretin P, Zeghnoun A, Mandereau-Bruno L, Croisier A, Cochet C, Ribéron J, Siberan I, Declercq B and Ledrans M. 2006. August 2003 Heat Wave in France: Risk Factors for Death of Elderly People Living at Home. Eur J Public Health., 16 (6): 583-591. doi:10.1093/eurpub/ckl063

Water Resources Research Center. 1987. Minnesota Drought. University of Minnesota. St. Paul, MN.

Western Regional Climate Center (WRCC). 2011. Minnesota Temperature 1890 – 2010: 12 month period ending in December. Generated online November 2011. Available online: http://www.wrcc.dri.edu/spi/divplot1map.html

Whitman, S., G. Good, E. Donoghue, N. Benbow, W. Shou, and S. Mou. 1997. Mortality in Chicago attributed to the July 1995 heat wave. American Journal of Public Health 87(9); 1515-1518.

Wisner B, Blaikie P, Cannon T and Davis I.2003 At Risk (Second Edition): Natural Hazards, people's vulnerability and disasters. Available at http://www.preventionweb.net/files/670_72351.pdf

Wu et al. 2008. Global Change and Ozone Air Quality.

Yang L, et al. 2003. An approach for mapping large-area impervious surfaces: Synergistic use of Landsat 7 ETM+ and high spatial resolution imagery. U.S. Geological Survey, U.S. Department of the Interior.

Zandlo, J. 2008. Observing the climate. Minnesota State Climatology Office. Available online: http://climate.umn.edu/climateChange/climateChangeObservedNu.htm

Zimmerman JL, Hanania NA. 2005. Chapter 111. Hyperthermia. In: Hall JB, Schmidt GA, Wood LD, eds. Principles of Critical Care. 3rd ed. New York: McGraw-Hill.

Ziska, L., K. Knowlton, C. Rogers, National Allergy Bureau, Aerobiology Research Laboratories, Canada. 2014 update to data originally published in: Ziska, L., K. Knowlton, C. Rogers, D. Dalan, N. Tierney, M. Elder, W. Filley, J. Shropshire, L.B. Ford, C. Hedberg, P. Fleetwood, K.T. Hovanky, T. Kavanaugh, G. Fulford, R.F. Vrtis, J.A. Patz, J. Portnoy, F. Coates, L. Bielory, and D. Frenz. 2011. Recent warming by latitude associated with increased length of ragweed pollen season in central North America. P Natl. Acad. Sci. USA 108:4248–4251.