2018 HENNEPIN COUNTY MULTI-JURISDICTIONAL HAZARD MITIGATION PLAN

Volume 2

Hazard Inventory (R)

01 February 2018

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SECTION 1	HAZARD CATEGORIES AND INCLUSIONS

1.1. Risk Assessment Process

Risk from natural hazards is a combination of hazard and vulnerability. The risk assessment process measures the potential loss to a community, including loss of life, personal injury, property damage and economic injury resulting from a hazard event. The risk assessment process allows a community to better understand their potential risk and associated vulnerability to **natural, intentional human-caused and unintentional human-caused hazards**. This information provides the framework for a community to develop and prioritize mitigation strategies and plans to help reduce both the risk and vulnerability from future hazard events.

This section describes the hazards that may impact Hennepin County and assesses their associated risk. Hazards that may affect Hennepin County are identified and defined in terms of their range of magnitude, spectrum of consequences, potential for cascading effects, geographic scope of hazard, historical occurrences and likelihood of future occurrences. The following hazard assessment information should be considered as new information and not an update from the 2010 plan. The Planning Team reviewed hazards from the previous plan and have identified hazards that need to be added. Several hazards from the 2010 plan were eliminated, **TABLE 1.1A** lists those removed with justification:

TABLE 1.1A

2010 Eliminated Hazard	Justification for Elimination
Dams	Although several dams exist across Hennepin County, none pose a significant threat to populations or property.
Earthquakes	This assessment will be a part of the future natural hazard build out.
Hazardous Materials	This assessment will be a part of the future plan un-intentional human-caused hazard build out.
Radiological	This assessment will be a part of the future plan un-intentional human-caused hazard build out.
Terrorism	This assessment will be a part of the future plan intentional human-caused hazard build out.
Transportation	This assessment will be a part of the future plan un-intentional human-caused hazard build out.

In addition, a thorough geospatial risk analysis was conducted using locally available parcel data and building values. Further, maps were provided where hazard boundaries and data existed. These improvements help to provide a more accurate assessment of risk in the county to develop mitigation actions.

1.2. FEMA Risk Assessment Tool Limitations

In 1997, FEMA developed the standardized Hazards U.S., or HAZUS model to estimate losses caused by earthquakes and identify areas that face the highest risk and potential for loss. HAZUS was later expanded into a multi-hazard methodology, HAZUS-MH, with new models for estimating potential losses from wind (hurricanes) and flood (riverine and coastal) hazards.

HAZUS-MH is a Geographic Information System (GIS) based software program used to support risk assessments, mitigation planning, and emergency planning and response. It provides a wide range of inventory data, such as demographics, building stock, critical facility, transportation and utility lifeline, and multiple models to estimate potential losses from natural disasters. The program maps and displays hazard data and the results of damage and economic loss estimates for building and infrastructure.

However, due to the limitations of the software (only estimates losses for earthquakes, hurricanes and floods), Hennepin County did not use this software in 2010 or this new update in 2017. To estimate losses, Hennepin County Emergency Management used the Hennepin County Critical Infrastructure and Facilities Critical Facility Index (CFI) Priority Ranking Aid. This CFI was provided to municipalities, Hennepin County Departments and special jurisdictions to assist in identifying critical infrastructure and facilities in their community and estimate the potential losses. This CFI takes into account all hazards that were identified in the Risk Assessment for the 2017 update. This section has been redacted due to sensitive information.

1.3. Justification of Hazard Inclusion

TABLE 1.3A provides the types of natural hazards that have been identified through analysis and assessment. **TABLE 1.3B** and **TABLE 1.3C** represent several identified unintentional and intentional human caused hazards. Unintentional and intentional human caused hazards will be prepared and built out for a future mitigation plan release.

TABLE 1.3A. Natural Hazards

Natural Hazards	Types	Justification for Inclusion
Geological	Landslide	Countywide vulnerable area, especially where steep slopes are located and heavy saturation occurs.
	Sink Hole	History of occurrences, poses danger to population and property
	Soil Frost	History of occurrences that have caused infrastructure damage
	Volcanic Ash	Historic volcanic eruptions (western states) have spread ash into Hennepin County. Future occurrences may also impact the county
Meteorological	Climate Change	There has been climate research done at the international level through the Intergovernmental Panel on Climate Change (IPCC) and also local through the Minnesota State Climatology Office.

	Tornado	Hennepin County has a strong history of tornadoes dating back to 1820. This hazard is a consistent threat to both life safety and property
	Winds, Extreme Straight-Line	Hennepin County has a strong history of derecho's dating back to 1904. The Storm Prediction Center (SPC) also highlights Minnesota as being highly impacted by derecho activity during the summer months.
	Hail	Hailstorms occur during severe convective storms and are an annual occurrence in Hennepin County. Very large hail has been recorded back as far as the National Weather Service has compiled data (1950). These storms pose a significant threat to people and infrastructure.
	Lightning	Lightning is a regular occurrence and is associated with thunderstorm activity. Hennepin County has a history of lightning deaths as well as damage to property and infrastructure
	Rainfall, Extreme	Hennepin County has had a history of extreme rainfall events and the occurrences are becoming much more frequent. The State Climatology Office has published sixteen-year research documents on Minnesota flash floods caused by extreme rainfall.
	Heat, Extreme	Extreme heat is an annual occurrence in Hennepin County and there have been several historic heat waves that have caused both deaths and injuries to our residents.
	Drought	Several historic droughts have occurred across Hennepin County dating back to 1863. These events cause severe impacts on agriculture and the economy as well as increasing wildfire potential.
	Dust Storm	Hennepin County has a history of dust storms going back to the 1930's. These days' dust storms are the cascading events of extreme drought.
	Cold, Extreme	Extreme cold temperatures are an annual occurrence in Hennepin County, with historic outbreaks dating back to the 1800's. These events pose significant threat to people and infrastructure.
	Winter Storm, Blizzard/Extreme Snowfall	Hennepin County has a history of winter weather dating back to the late 1800's. Varying degrees of severity occur in Hennepin County due to the

		different topography, with the worst conditions occurring in western Hennepin County.
	Winds, Non-Convective High	Although rare, extreme wind-producing non-convective event may affect well over 100,000 square miles with wind damage, and may produce extreme impacts over tens of thousands of square miles
	Ice Storm	Several ice storms have occurred in Hennepin County dating back to the 1930's. These storms have caused great impact to infrastructure and people. The cascading effect of power outages is another threat that has occurred with past ice storms.
Hydrologic	Flooding, River	Several historic flood events have occurred due to the Mississippi, Crow, and Minnesota River in Hennepin County.
	Flooding, Urban	Urban flooding is a consistent problem in Hennepin County, due to torrential rainfall associated with thunderstorm activity.
Biologic	Animal infectious disease	Annual occurrence
	Human infectious disease	Annual occurrence
	Insect infestation	Annual occurrence
	Plant infectious disease	Annual occurrence
	Wildland Fires	Wildland fires occur yearly in Hennepin County, most right before spring green-up (March-May) in the western portion of Hennepin County.

TABLE 1.3B. Unintentional Human Caused Hazards

Unintentional Human Caused Hazards	Types	Justification for Inclusion
Advanced Technology Research	Artificial Intelligence	**THIS SECTION WILL BE PREPARED AT A FUTURE MITIGATION PLAN RELEASE**
	Biotechnology	
Ecological Catastrophic	Pollinator collapse	
Structural Failure	Fire	
	Explosion	
	Collapse	
Transportation Accidents	Aviation	
	Rail	
	Roadway	
	Maritime/Riverine	
	Pipeline	

Utility Failure	Electrical Blackout	
	Water Supply Disruption	
	Communications/ data disruption	
	Energy supply Disruption	
Toxic Industrial Compound (TIC) Release		
Nuclear Accident		

TABLE 1.3C. Intentional Human Caused Hazards

Intentional Human Caused Hazards	Types	Justification for Inclusion
Civil Disturbance	Looting	**THIS SECTION WILL BE PREPARED AT A FUTURE MITIGATION PLAN RELEASE**
	Riots	
Cyber Activity		
Vandalism and Sabotage		
Terrorism	Small Arms	
	Improvised Explosive Device	
	Chemicals and Toxins release	
	Biological Agent release	
	Radiological Dispersal	
	Nuclear device detonation	
Insurgency		
Conventional Warfare		
Nuclear Warfare		

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SECTION 2	DISASTER DECLARATION HISTORY AND RECENT TRENDS

2.1. Disaster Declaration History

One method to identify hazards based upon past occurrence is to look at what events triggered federal and/or state Disaster Declarations in Hennepin County. Disaster Declarations are granted when the severity and magnitude of the events impact surpass the ability of the local government to respond and recover. Disaster assistance is supplemental and sequential. When the local government's capacity has been surpassed, a state disaster declaration may be issued, allowing for the provision of state assistance. If the disaster is severe enough that both the local and state government's capacity is exceeded, a Federal Declaration may be issued, allowing for the provision of Federal disaster assistance.

It is important to note that the Federal government may issue a Disaster Declaration through the U.S. Department of Agriculture (USDA) and/or the Small Business Administration (SBA), as well as through FEMA. The quantity and types of damages are the determining factors. Listed below in **TABLE 2.1A** are the previous Disaster Declarations that have occurred in Hennepin County. There have been four presidential declarations since 2010.

TABLE 2.1A. FEMA Declared Disasters (1965-2017)

Date	Disaster Type	Assistance Type	Disaster Number
November 2, 2016	Severe Storms and Flooding	Individual Assistance	DR-4290
July 21, 2014	Severe Storms, Straight Line Winds, Flooding, Landslides, and Mudslides	Public Assistance	DR- 4182
July 25, 2013	Severe Storms, Straight Line Winds, and Flooding	Public Assistance	DR- 4131
June 7, 2011	Severe Storms and Tornadoes	Public Assistance	DR- 1990
March 19, 2010	Flooding	Public Assistance	EM- 3310
August 21, 2007	I-35W Bridge Collapse	Public Assistance	EM-2378
September 13, 2005	Hurricane Katrina Evacuation	Public Assistance	EM- 3242
May 16, 2001	Flooding	Individual Assistance	DR- 1370
June 23, 1998	Severe Storms, Straight-Line Winds and Tornadoes	Public Assistance	DR- 1225
August 25, 1997	Flooding	Individual/Public Assistance	DR1187
April 8, 1997	Severe Storms/Flooding	Individual/Public Assistance	DR- 1175

August 6, 1987	Severe Storms, Tornadoes, Flooding	Individual/Public Assistance	DR- 797
July 8, 1978	Severe Storms, Tornadoes, Hail, Flooding	Individual/Public Assistance	DR- 560
June 17, 1976	Drought	Public Assistance	EM-3013
April 18, 1969	Flooding	Individual/Public Assistance	DR- 255
April 11, 1965	Flooding	Individual/Public Assistance	DR-188

SECTION 3	CLIMATE ADAPTATION CONSIDERATIONS

3.1. Climate Adaptation

Climate includes patterns of temperature, precipitation, humidity, wind and seasons. Climate plays a fundamental role in shaping natural ecosystems and the human economies and cultures that depend on the. Climate adaptation refers to the ability of a system to adjust to climate change to moderate potential damage, to take advantage of opportunities, or to cope with the consequences. *The International Panel on Climate Change* (IPCC) defines adaptation as the, "*adjustment in natural or human systems to a new or changing environment*". Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

3.2. Hennepin West Mesonet (HWM)

In order to adapt to climate change, Hennepin County has built the Hennepin West Mesonet, a network of remote sensors which provide highly-accurate, near real-time measurements of weather, soil and water conditions. Recent experiences across the Twin Cities metro area reveal a long-standing vulnerability to dangerous weather or human-caused conditions that form very quickly without clear advance indications. Fatal tornadoes in Rogers, MN (*2006*) and in North Minneapolis, MN (*2011*) both point to a need for more complete and rapid surface observations from a network of sensors spread across the area. A fatal landslide in Saint Paul, MN (*2013*) also shows that near real time soil temperature and saturation data across the metro could be useful in providing alerts for evolving dangerous conditions. Other vulnerabilities exist in our area to rapid-onset flash flooding, straight-line winds or hazardous materials releases which require many sensors with quick detection capability to provide useful pubic warning or evacuation decision-making.

The Hennepin West Mesonet delivers normal at different temporal resolutions, thus providing more precise climate monitoring. Through climate monitoring, the HWM provides an essential service and benefit of observing and precisely detecting impacts on the environment and ecosystems both at the geospatial and temporal scale in Hennepin County. Archived data and current observations provide consistent and high-quality information from decision-makers and researchers, information that can be utilized for development of research and prediction models, improving understanding of climate variability, advancing public climate education, and supporting development of mitigation and/or adaptation measures for local communities.

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SECTION 4	COMPREHENSIVE NATURAL HAZARD ASSESSMENTS

NATURAL HAZARD PROFILES

4.1. Geological Hazards

4.1.1.	Hazard Assessment: LANDSLIDES

4.1.1.1. Definition. A landslide is the downward movement of rock, soil or other debris along a slope. Other terms used for landslides are debris flow, earth flow, mudslide, slump, slope failure, mass wasting, and rock fall. The rate of landslide movement ranges from sudden to very slow, and may involve small amounts of material up to very large amounts. The kinds of movement include falling, sliding and flowing. Material can move as an intact mass or become significantly deformed and unconsolidated. The slopes that have landslides can range from near vertical to gently rolling with slopes above 30% having the highest susceptibility.

4.1.1.2. Range of magnitude

Further work is needed among the Hennepin County landslide assessment team to develop range of magnitude

4.1.1.3. Spectrum of Consequences

4.1.1.3.1. PRIMARY CONSEQUENCES:

4.1.1.3.1.1. Transportation: Mobility is frequently stopped or slowed by landslides. When at the foot of slopes, roads and highways can be impacted by fallen rock, soil flows and landslide debris. When routes are at the crest of slopes, surfaces may be undercut by slides and fall away leaving voids and gaps in the road. Railroads are similarly impacted by landslides. The practice of cut and fill in road and rail grade construction can increase susceptibility to this problem. Besides direct damage to surface transportation routes, secondary impacts can occur if vehicles carrying hazardous materials rupture if struck by slides.

4.1.1.3.1.2. Electric utilities: Electric service lines often follow alongside roads, including their routes through valleys and ravines or along the crests of slopes. This makes them vulnerable to disruption from landslides. Cut power lines are a frequent feature of landslide activity. Landsides impact both lines suspended from utility poles and buried power lines.

4.1.1.3.1.3. Water, sanitary and storm sewer services: Cracked, broken or leaking water or sewer lines often have a significant role in triggering landslides in susceptible areas. Inspections and maintenance of lines in vulnerable locations should be a priority in order to reduce risk. Water and sewer lines are also vulnerable to damage and destruction by landslide events.

4.1.1.3.1.4. Energy pipelines: Gas lines and other energy pipelines that pass through landslide susceptible areas may become weakened or severed by slide action. Damages may be caused by direct physical impacts or by indirect transmission of stresses through soil to the pipeline causing weaknesses or deformation of the lines.

4.1.1.3.1.5. Telecommunications: Telecommunications cables that pass through landslide susceptible areas may become weakened or severed by slide action. Damages may be caused by direct physical impacts or by indirect transmission of stresses through soil to the cable causing weaknesses or deformation of the lines. Fiber optic lines are particularly susceptible to deformation which can cause erratic signals or total signal loss.

4.1.1.3.1.6. Structural damage: Landslides impacts to structures ranges from rapid catastrophic destruction resulting from a landslide impact to gradual degradation of structures from slow earth movements. Complex load factors act on structures that are subject to landslide forces. Engineering assessment of compromised structures is vital to both response and recovery phases of a landslide incident. Landslide impacts to structures is both a life-safety hazard and can also be an occasion for costly property damage.

4.1.1.3.1.7. Recreational impacts: Parks and trails are frequently placed in areas subject to landslides. Often parks or trails are in scenic areas in ravines or valleys associated with rivers with natural slopes being a main feature. They may also be part of former railroad rights-of-way that have been abandoned. Human-modified slopes or other historic disruptions of natural soils and terrain can elevate landslide susceptibility in parklands. Slides in parks and trails is a risk to lives and safety, as well as a costly disruption to recreation activities.

4.1.1.3.2. SECONDARY CONSEQUENCES:

4.1.1.3.2.1. Hazardous material spill or release: If cut by a landslide, pipelines may release hazardous liquids or gasses, or polluting materials that can threaten lives, impact property or harm the environment as a secondary hazard after the landslide.

4.1.1.3.2.2. Fire or explosion: In certain instances, landslides may trigger fires or explosions at the site of buildings or other impacted structures, or where pipelines or service lines carrying gas or other flammable material.

4.1.1.4. Potential for Cascading Effects

4.1.1.4.1. Life-Safety: Landslides can result in deaths and have done so in Hennepin County (1955) and adjacent metro counties (2013). Injuries have resulted in numerous other instances, as well as close calls. The landslide at Fairview-Riverside hospital in Minneapolis (2014) narrowly missed pushing passing motorists on West River Road into the Mississippi River, for instance.

4.1.1.4.2. Infrastructure Destruction: Landslides can impact many kinds of critical infrastructure. Linear infrastructure such as roads, highways, railroads, pipelines, electric power lines and telecommunications cables are particularly vulnerable to slides that cross their paths. Water and wastewater infrastructure is not only vulnerable to slides as a linear system, but may also help trigger landslide activity if a break occurs in water, sewer or storm sewer lines at sites that have other susceptibility factors. Point infrastructure located at susceptible sites anywhere between the crest to the foot of slopes are also vulnerable.

4.1.1.4.3. Property Damage: Homes and businesses have been damaged or destroyed by landslides in Hennepin County and surrounding counties. Lack of detailed landslide investigations and awareness in some cases have led to development on susceptible terrain. The fact that landslides are not covered by insurance policies has led to often catastrophic financial losses for homeowners and businesses that are hit. Expensive litigation has also often resulted from these incidents between property owners and cities.

4.1.1.5. Geographic Scope of Hazard

Landslide activity depends on certain localized factors (see above critical values) that result in an uneven distribution of landslides across Hennepin County. In general, Hennepin County landslide activity occurs in the valley walls of the Minnesota, Mississippi and Crow Rivers and their tributaries. Some of the exposed glacial sediments and bedrock layers in these valleys are unstable and subject to precipitation or spring-induced landslides. In the interior of Hennepin County, small landslides happen in steep slopes in glacial sediments that are found along streams, ravines, lakeshores, and wetlands. Artificially steepened slopes, often with disrupted soils and fills, also have been sites for landslides in Hennepin County. A Hennepin County Landslide Hazard Atlas is in development and is set for release in late 2018.

4.1.1.6. Chronologic Patterns

Further work is needed among the Hennepin County landslide assessment team to develop Chronological Patterns

4.1.1.7. Historical Data

4.1.1.7.1. HISTORICAL RECORD: Hennepin County Emergency Management commissioned an assessment of historic landslide activity in the county using archival data and historic news accounts. There are around two dozen landslides in Hennepin County that were documented in written accounts including a known location and date.

4.1.1.7.2. PRE-HISTORIC EVIDENCE: Hennepin County Emergency Management commissioned an assessment of pre-historic landslide activity in the county using LiDAR (Light Detection and Ranging) imagery. There are over one thousand sites in Hennepin County with landslide evidence that have been discovered through imagery analysis.

4.1.1.8. Future Trends

4.1.1.8.1. TRENDS AND PROJECTIONS: The most significant trigger for landslide activity in Hennepin County is precipitation. Documented trends in precipitation in Minnesota, as well as projections into the future show an increase in overall rainfall, plus an increase in intense precipitation events. Recent landslide activity in Minnesota and Hennepin County has risen. It appears likely that landslide activity will continue to grow in tandem with precipitation trends.

4.1.1.8.2. EVENT PROBABILITIES: More analysis of the recently developed data is needed to determine landslide event probabilities in Hennepin County.

4.1.1.9. Indications and Forecasting

Further work is needed among the Hennepin County landslide assessment team to develop modeling and forecasting methods.

4.1.1.10. Detection & Warning

Additional work is needed among the Hennepin County landslide assessment team to develop detection and warning criteria. Indications of changes in key factors will be accomplished in large part by the Hennepin-West Mesonet network of environmental sensors.

4.1.1.11. Critical Values and Thresholds

4.1.1.11.1. Slope. Also called the angle of repose, slope is a critical factor for landslide susceptibility. In Hennepin County, landslide activity starts to increase above 20% slope, and is most numerous on slopes between 30-40%. Slopes may be either natural or artificially created by human activities.

4.1.1.11.2. Soil type: Soil type is important to landslide susceptibility for several reasons. Differences in the porosity and permeability of soils is important since it describes the degree to which soil types will either slowly retain or quickly shed water. Other characteristics such as soil structure may contribute to slope failure. Many soils in Hennepin have been disrupted or altered in some way by human activities.

4.1.1.11.3. Soil moisture: Soil moisture is a critical factor in Hennepin County landslides. Among other things, when water replaces air within soil pores, the overall weight of the soil increases.

Increasing the weight of near surface soils can increase the likelihood of the material moving downslope and forming a landslide. The Hennepin County landslide assessment is developing specific soil moisture criteria for alert purposes.

4.1.1.11.4. Precipitation. Precipitation is one of the most critical factors in triggering landslides in Hennepin County. Duration, intensity and recurrence of precipitation are important elements in precipitation-initiated landslide events. The Hennepin County landslide assessment is developing specific precipitation thresholds for alert purposes.

4.1.1.11.5. Springs. Springs discharge water along slopes, increasing erosion and helping to trigger landslides. Springs in Hennepin have been mapped in detail.

4.1.1.11.6. Bedrock. The depth from the surface to bedrock is an important factor in some kinds of slides. Exposed bedrock is required for rock falls for instance. A shallow depth to bedrock may also facilitate flows and other forms of slides as well.

4.1.1.11.7. Surface conditions: Vegetation on slopes usually assists in stabilizing them against failure. Plants with deep root systems, often native species, are recommended to help slow slope erosion. Conversely, removal of vegetation that results in bare and exposed soil increases the risk of landslides and mudslides.

4.1.1.11.8. Soil temperature: The action of winter and spring freeze-thaw cycles seems to help trigger some rock falls or topples. Thus, these types of landslides are the only ones that appear to happen outside of the normal rainfall/thunderstorm season of Hennepin County. The freeze-thaw cycles allow water, trapped in voids and crevices in rock, to expand and push rock apart, sometimes triggering a fall.

4.1.1.12. Prevention

Further work is needed among the Hennepin County landslide assessment team to develop prevention methods.

4.1.1.13. Mitigation

4.1.1.13.1. Avoidance (Prevention). The most effective mitigation measure against landslide fatalities, injuries, infrastructure disruption and property loss is avoiding development and certain human activities at sites prone to landslides. This is a preventive action. Avoidance may be accomplished through evidence-based zoning policies that utilize local area landslide hazard assessments that trigger site-specific landslide investigations when appropriate if development or other uses are proposed at sites inside identified hazard zones. Specific actions include avoiding cutting into slope sides or at the food of slopes, and not placing excessive weight on the top of slopes by erecting structures there.

4.1.1.13.2. Education and public alerts. Education of zoning officials, land owners and need accurate local information in order to make sound decision regarding their development and activities in landslide susceptible terrain. A simple knowledge of landslide risk also sets the foundation for appropriate action when a public alert is issued. Public alert thresholds, messages and distribution methods must be developed.

4.1.1.13.3. Active mitigation methods. Geometric methods include changes in slope angle to reduce the chances of landslides. Hydrological methods consider surface, shallow and deep water drainage and attempt to improve the ability of landslide-susceptible sites to drain water effectively. Finally, mechanical methods include the use of rock anchors, netting, retaining walls, or pilings. In general, these methods are expensive and are suitable only of sites of limited size in areas where development is of high importance.

4.1.1.14. Response

Further work is needed among the Hennepin County landslide assessment team to develop Response methods.

4.1.1.15. Recovery

Further work is needed among the Hennepin County landslide assessment team to develop Recovery methods.

4.1.1.16. References

4.1.2.	Hazard Assessment: SINKHOLE

4.1.2.1. Definition.

A **sinkhole** is a bowl-shaped depression in the land surface. Sinkholes are also called **subsidence**, which is a downward settling of the surface without any horizontal movement. Sinkholes result from natural processes where near-surface carbonate bedrock is dissolved by water to form underground spaces, also called voids. These voids typically form along existing joints or cracks in the rock that aid the movement of water. Some voids grow toward the surface where infiltrating surface waters meet and flow downward into the drain of the void. This action weakens the rock. Eventually, the weight of overlying materials can result in a collapse. Areas favorable for sinkhole development are called **karst** terrain. Certain human activities may speed up the natural sinkhole processes in karst areas. Human activities outside of normal karst terrain can also trigger unexpected human-caused ground collapses in materials not usually prone to sinkholes.

4.1.2.2. Range of magnitude

Unknown, pending conclusion of the Hennepin County Emergency Management-sponsored sinkhole hazard assessment in 2020.

4.1.2.3. Spectrum of Consequences

4.1.2.3.1. PRIMARY CONSEQUENCES:
Sinkholes and other land subsidence can cause significant direct damage to buildings, roads, water supply systems and other infrastructure. The loss of land usable for farming or other development is another consequence of sinkhole activity. Finally, groundwater contamination is a significant consequence of karst and sinkhole activity. Subsurface water flow in karst areas creates a situation where surface water, along with their contaminants, quickly travel deep into aquifers without significant filtration. The problem is worsened when people use sinkholes as garbage dumps, which was formerly a common practice in the United States.

4.1.2.3.2. SECONDARY CONSEQUENCES:

4.1.2.3.2.1. Disease. Dumping of wastes into sinkholes maybe a source of disease. A disease outbreak in Harmony, Minnesota (Fillmore County) was traced to a sinkhole used as a disposal point for human waste.

4.1.2.3.2.2. Dam failures. There have been instances of dams and other water-control infrastructure being undermined by sinkholes and other karst activity.

4.1.2.3.2.3. Fires or explosions. When structures, or infrastructure such as pipelines are impacted by sinkholes and gas lines are compromised, fires and explosions are possible.

4.1.2.4. Potential for Cascading Effects

In Minnesota, most sinkholes are located in rural areas and develop very slowly. These sinkholes are not dangerous and they do not cause much destruction except for the loss of crop land. When sinkholes happen in developed urban areas however, they have the potential to be much more costly and, in some cases, even dangerous. The active karst areas in southeast Hennepin County are located in places with concentrated developments of housing, businesses, schools and infrastructure. The potential for destructive sinkhole events in Hennepin County has not been adequately assessed. Hennepin County Emergency Management is initiating a study of sinkhole hazards in the county that is expected to be complete by 2020.

4.1.2.5. Geographic Scope of Hazard

The southeastern three-quarters of Hennepin County is underlain by carbonate bedrock, and is karst terrain. The western and northern limits of this area begin in the south around Excelsior and extend northward into Medina, then eastward into Brooklyn Center. Most of this area is comprised of *covered karst* which has overlying glacial material more than 100 feet in depth. An area with pockets of *transitional karst* which has overlying glacial material between 50 and 100 feet thick is roughly bounded in the south by Edina, west to Wayzata, and northeast to Brooklyn Center. *Active karst* is found in mostly along the Mississippi River from North Minneapolis south to Fort Snelling. Scattered outlying pockets of active karst can be found westward from Golden Valley south to St. Louis Park. Active karst areas have less than 50 feet of overlying material covering them.

Note: Other types of land subsidence are directly caused by human activities and are dealt with in the human-caused, industrial/technological section of this hazard assessment. These include water or sewer system breaks that cause sinkholes, or collapse of underground tunnels

4.1.2.6. Chronologic Patterns

Unknown, pending conclusion of the Hennepin County Emergency Management-sponsored sinkhole hazard assessment in 2020.

4.1.2.7. Historical Data

The Seven Oaks Park in south Minneapolis is a sinkhole. The surface depression is approximately 300 feet wide and over 20 feet deep. The time of formation of the sinkhole is unknown, but predates the construction of the structures around it. Seven Oaks Park is located between E 34th Street and E 35th Street at 47th Avenue South in Minneapolis (USNG 15T VK 83754 76384). Other possible sinkholes are nearby, but await more definitive confirmation.

4.1.2.8. Future Trends

Unknown, pending conclusion of the Hennepin County Emergency Management-sponsored sinkhole hazard assessment in 2020.

4.1.2.9. Indications and Forecasting

Unknown, pending conclusion of the Hennepin County Emergency Management-sponsored sinkhole hazard assessment in 2020.

4.1.2.10. Detection & Warning

Unknown, pending conclusion of the Hennepin County Emergency Management-sponsored sinkhole hazard assessment in 2020.

4.1.2.11. Critical Values and Thresholds

4.1.2.11.1. Bedrock material: Areas susceptible to sinkholes (karst terrains) are underlain by water-soluble, but relatively impermeable bedrock such as limestone (calcium carbonate). Soluble rocks dissolve when exposed to certain acids, including acidic water. Over time, acidic water flowing through joints and cracks will dissolve and remove large amounts of soluble rock creating many void spaces. In more unusual instances, sandstones or even quartzite may develop sinkholes. In these cases the bedrock is more permeable, but less soluble. Slower sinkhole development may occur in these rocks.

4.1.2.11.2. Water acidity: Acidic surface water and groundwater is required for natural sinkhole formation as the agent that dissolves soluble bedrock. Pure water has a pH of 7.0, which is neutral – neither acidic nor base. However water in nature is not pure. Instead it contains natural impurities which make it acidic. Unpolluted rainwater has a pH of around 5.6 (acidic). Rainwater in Minnesota contains atmospheric pollutants which further lower the pH, increasing acidity. Once at the surface, water can become further acidified by exposure to nitrogen fertilizers or other chemicals. When this water infiltrates into the bedrock it begins to gradually dissolve any carbonate rocks.

4.1.2.11.3. Bedrock depth: In order for a void to cause a collapse of the overlying surface material it must be close to the surface. *Active karst* areas have carbonate bedrock less than 50 feet below the surface. *Transitional karst* areas have carbonate bedrock covered by material between 50 and 100 feet. In some instances sinkholes can occur in these conditions as well. *Covered karst* areas have more than 100 feet of overburden. Sinkholes are unlikely to develop in such deep conditions.

4.1.2.11.4. Bedrock topography. Once water penetrates the soil, it will arrive at the bedrock layer. Typically, the bedrock is much less permeable than the overlying unconsolidated soils which promotes lateral water flow. The water will flow according to the topography of the bedrock finding crevices and valleys that collect water until a penetration point can be found into the bedrock.

4.1.2.11.5. Joints, fractures and bedding planes: These features provide easy routes for water to travel through the rock. As water moves through this network of joints, fractures and bedding planes, chemical action of the acidic water dissolves the bedrock. Joints and fractures are often oriented in parallel and perpendicular patterns. Because of this, voids and sinkholes also are often aligned to follow these patterns.

4.1.2.11.6. Water table: Fluctuations in ground water levels can affect sinkhole activity. Abrupt changes in ground water level can induce sinkholes. Ground water drawdown often increases sinkhole activity.

4.1.2.11.7. Construction and development. Human development activities that add extra weight and pressure to land surfaces by construction of new buildings and other infrastructure may accelerate sinkhole formation. The alteration of surface and subsurface drainage flows due to human development may also accelerate sinkhole formation by increasing the flow of water through sinkhole drains. Water and sewer lines in karst areas are susceptible to damage from sinkholes and other land subsidence. When water or sewer lines leak or break, the released water may enter sinkhole systems and quickly enlarge voids, accelerating sinkhole formation.

4.1.2.12. Prevention

4.1.2.12.1. Avoidance The most effective prevention/mitigation measure against sinkhole fatalities, injuries, infrastructure disruption and property loss is avoiding development and certain human activities at sites prone to sinkholes. This is a preventive action. Avoidance may be accomplished through evidence-based zoning policies that utilize local area sinkhole hazard assessments that trigger site-specific sinkhole risk investigations when appropriate if development or other uses are proposed at sites inside identified hazard areas. Zoning-based measures would be challenging in Hennepin County because much of the karst areas have already been developed.

4.1.2.13. Mitigation

4.1.2.13.1. Education. Education of zoning officials, land owners need accurate local information in order to make sound decision regarding their development and activities in sinkhole susceptible terrain. These require detailed sinkhole hazard maps. Hennepin County Emergency Management (HCEM) will commission an assessment in the near future with a projected map release by 2020.

4.1.2.14. Response

Unknown, pending conclusion of the Hennepin County Emergency Management-sponsored sinkhole hazard assessment in 2020.

4.1.2.15. Recovery

Unknown, pending conclusion of the Hennepin County Emergency Management-sponsored sinkhole hazard assessment in 2020.

4.1.2.16. References

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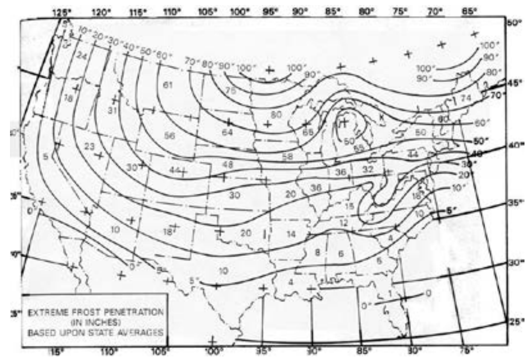
4.1.3.	Hazard Assessment: SOIL FROST

4.1.3.1. Definition.



Soil frost is caused when water, which is present as a component of soil, freezes into pore ice. The depth to which this freezing penetrates is called the *deep frost*. Some soils are vulnerable to *frost heaving*, which is the vertical displacement of the surface due to frost expansion or the development of ice lenses. *Melt collapse* happens when the ice lenses melt. These effects can damage roads and building foundations and other infrastructure. Deep penetration of frost can also have a devastating impact on critical buried infrastructure, such as water and wastewater pipes. In extreme cases, fire hydrants and fire sprinkler water supplies may freeze. Hard *impervious frost* layers in the soil also can worsen spring time rain and snowmelt flooding by not allowing water to penetrate the soil and increasing run-off.

4.1.3.2. Range of magnitude

Unknown, pending conclusion of the Hennepin County Emergency Management-sponsored soil frost hazard assessment in 2020.

4.1.3.3. Spectrum of Consequences

4.1.3.3.1. PRIMARY CONSEQUENCES

4.1.3.3.1.1. Water utilities: In Hennepin County, water service lines are typically buried between 78 to 90 inches (198.1 to 228.6 centimeters) deep. This depth is usually protects these lines against freezing. When particularly deep frost is formed, however, water service lines may freeze, cutting off water services to residences, businesses and government facilities. Bottled water delivery is often the response of choice while awaiting water service restoration. Water service freezing not only stops the flow of potable water to an address, it may also interrupt fire protection systems such as sprinklers or standpipes. Water mains, which are buried deeper than service lines, are less likely to freeze. If they freeze, then fire hydrant services also are interrupted. Thawing frozen water lines is difficult and time consuming. It requires special equipment and experience. Some methods may cause structural fires. In widespread instances of frozen water lines, service may be cut for days to weeks. Without intervention, frozen water service lines in Hennepin County would thaw by May. Service line freezing may be prevented by keeping a pencil-sized flow of cold tap-water moving through the system at all times. Prevention is usually done at the request of the local water utility.

4.1.3.3.1.2. Wastewater services: In general, municipal sewer lines have similar depth requirements as water service lines to prevent frost damage or disruption. Sewer lines typically have fewer freeze problems during deep frost events than water lines, however. Rather than frost causing problems for municipal sewer systems, a bigger issue seems to be impacts to household septic systems.

4.1.3.3.1.3. Energy pipelines: Gas and other pipelines are vulnerable to the effects of frost. According to data from the Pipeline and Hazardous Materials Safety Administration (PHMSA), 82% of cold weather failures of distribution pipelines in the US (1984 through 2014) were caused by frost heave.

4.1.3.3.1.4. Communications: Buried fiber optic cables are susceptible to impacts from frost. This occurs when water that has infiltrated the fiber optic conduit freezes. The most vulnerable areas were sites were cables were shallow or exposed near bridges. While freezing has no impact on copper cables, fiber optic cables may be bent by the expansion of the ice. Various levels of signal degradation may occur, including complete failure. As a countermeasure, some communication companies have injected their conduit with anti-freeze compounds.

4.1.3.3.1.5. Structural damage: Frost heave of soils can cause significant damage to structures including cracked foundations or slabs and other effects from ground movement.

4.1.3.3.1.6. Transportation: Roads and highways are impacted frost action. Differential frost heaves are create blisters in pavement that leads to cracking and potholes. Frost can block proper drainage and lead to additional problems. Road load-bearing capacity is affected by freeze-thaw cycles.

4.1.3.3.2. SECONDARY CONSEQUENCES:
Frost induced breaks in gas or oil pipelines can cause fires or explosions.

4.1.3.4. Potential for Cascading Effects

4.1.3.4.1. Specific sites. Deep frost can impact buried infrastructure that carry water, wastewater, energy or communications causing service interruption by freezing or by physical damage. Frost heaving can also cause damage to buildings and other structures. These damages are highly dependent on localized conditions leading to impacts that area variable from address to address. Frost depth impacts may be widespread but spotty.

4.1.3.4.2. General areas. Deep frost can create a frozen and temporarily impervious layer of soil across wide regions which limits infiltration of snow-melt water and rainwater in springtime. This additional runoff worsens springtime flooding across river basins and stream watersheds.

4.1.3.5. Geographic Scope of Hazard

All areas of Hennepin County and the State of Minnesota are vulnerable to soil frost during winter months. Minnesota and the adjacent state of North Dakota are the center of deep frost activity in the 48 contiguous United States. While frozen soils are routine in all parts of Minnesota, problems occur when frost penetrates deeper than normal. The Minnesota State Building Code (MSBC) Rule 1303.1600 places construction frost depth in Hennepin County at 42 inches (106.7 centimeters).

4.1.3.6. Chronologic Patterns

Unknown, pending conclusion of the Hennepin County Emergency Management-sponsored soil frost hazard assessment in 2020.

4.1.3.7. Historical Data

4.1.3.7.1. Comprehensive. Hennepin County Emergency Management (HCEM) has not yet systematically investigated historical records of local frost depth. Precise frost measurements using frost tubes or other sensors are unlikely to have been conducted anywhere in Hennepin County prior to the HCEM program which started in 2015. The nearest historic soil frost records are probably measurements taken at the University of Minnesota, Saint Paul campus. These St. Paul records are for frost under sod. It is possible that written historical accounts of frost depth and their effects might be found in records of municipal utility providers. These records, if discovered, would probably be for frost under pavement which impacted water lines and other utilities.

4.1.3.7.2. Winter of 2013-2014. The coldest Hennepin County winter since 1978-1979 occurred in 2013-2014 with a sustained three-month cold snap. The mean temperature for the months of December, January and February was 9.8F degrees at MSP airport. The normal for this time period is 18.7F degrees. More snow fell than average during the period as well (57.2 inches three-month total). Most of it fell late in the period. Frost was pushed much deeper than average. Anecdotal reports by public work crews working on frozen water service lines reported frost as deep as 7 to 8 feet in Plymouth. Twelve cities, not including Minneapolis, provided information regarding service interruptions. In these cities were a total of 324 water freeze up incidents, mostly service lines. In addition 1 hydrant froze, 2 water mains, and 4 sewer lines also became frozen. The longest outages were over one week. Residences, businesses, care facilities, and government buildings were impacted. In several instances, cities had to distribute bottled water to affected residences.

4.1.3.7.3. Pre-Historic Evidence:
Unknown. HCEM has not found any research regarding pre-historic frost depth in Hennepin County.

4.1.3.8. Future Trends

Undetermined. Climate change is having a significant impact on Minnesota and Hennepin County. Forces generated by climate change are sometimes at odds over the net effect experienced in this area during any particular winter. For instance, there has been an overall warming trend in Minnesota winters, including a shorter winter season and higher average temperatures. More recently, prolonged outbreaks of extreme cold air have impacted Minnesota and Hennepin County. These include the winter of 2013-2014 and the winters of 2016-2017 and 2017-2018. These cold outbreaks appear to be related to warming in the Arctic that has weakened the Polar Jet Stream. The weakened jet stream is less able to contain cold Arctic air in high latitudes and block it from streaming south. Some scientists theorize that prolonged outbreaks of extreme cold polar air may be a recurring feature of future winters in Minnesota. When coupled with low or no-snow cover conditions, outbreaks of extreme cold may push frost deeper into the soil.

EVENT PROBABILITIES: Unknown. Further research is needed to determine trends and probabilities of future deep soil frost events in Hennepin County.

4.1.3.9. Indications and Forecasting

Additional study is needed to develop deep soil frost event models and forecasts for Hennepin County. Adequate weather forecasting already exists and would certainly be a major factor in any future soil frost forecasts. Better data on the behavior of frost in local soils under various temperature, surface material, soil moisture and snow cover conditions is required to develop models and forecasts. Hennepin-West Mesonet data will provide much of the needed information.

4.1.3.10. Detection & Warning

In 2015, following the disruptive winter of 2013-2014 when hundreds of water service lines were frozen, Hennepin County Emergency Management (HCEM) began to install a network of manually-read frost tubes at locations around Hennepin County. When possible, two frost tubes were installed at the same site. One tube was for measuring frost depth under sod, and the other for frost depth under pavement because of the significant differences between the two. Frost tubes are usually located near a Hennepin-West Mesonet sensor station so that weather factors can be compared to the frost depth at the site. The measurements, taken at least weekly, can provide indications that the frost is pushing deeper than normal and is beginning to threaten water and sewer services, fire protection capabilities, and other vital services. When appropriate, HCEM will send out alerts to public works officials that frost may threaten their water and sewer infrastructure.

4.1.3.11. Critical Values and Thresholds

4.1.3.11.1. Air temperature: Air temperatures below freezing (32F/0C) are required to initiate soil frost formation. A freezing index based on degree-days of freezing may be used to roughly estimate frost depth potential in an area.

4.1.3.11.2. Pavement. Human-made surfaces, such as concrete or asphalt roadways create ideal conditions for exceptionally deep frost penetration into soil. The differences between frost depth under paved roads and frost depth under natural sod is large enough to produce a few feet of difference at the same site. Therefore, measurements should specify of they are taken under pavement or under sod. Factors such as the thermal conductivity of pavement and the removal of snow cover combine to push frost deep into the underlying soils. This is important because a lot of buried infrastructure is underneath immediately adjacent to roadways, increasing their vulnerability to frost.

4.1.3.11.3. Surface albedo: Surface albedo is the ratio of irradiance of solar energy reflected to the irradiance of solar energy absorbed by a surface. Asphalt, dark soils, turf grasses and forests have low albedo. Snow cover, sand, and winter prairie grasses have higher albedo. The albedo of the primary surface is important because it influences the snow cover characteristics of the site. Snow cover is a central factor is controlling frost depth.

4.1.3.11.4. Soil type: Different soil types freeze at different rates. Frost tends to penetrate less in clay (heavy textured) soils and more deeply in silty or sandy (lighter textured) soils. Inorganic soils with >3% by weight of grains finer than 0.02 millimeter in diameter (silts, silty sands and clays) form frost lenses more easily and have a very high susceptibility to frost heaves.

4.1.3.11.5. Moisture content: Soil moisture effects the initial freezing of soil because of the increased heat capacity and thermal conductivity of the soil surface. The initial freezing point of soil is usually delayed with increasing amounts of soil moisture. As winter progresses, the soils that have started with greater amounts of water filling pore spaces experience greater overall frost depths due to increased thermal conductivity since air is a less efficient conductor of heat than water. Water tables within 10 feet of the surface are a contributing factor for frost heaves.

4.1.3.11.6. Snow cover: The insulating effect of snow cover is a key factor in slowing the penetration of frost into the soil. Each foot of undisturbed snow cover typically reduces the depth of soil freezing by an equal amount. Snow cover is a function of the amount of snowfall received at a location, along with the type of surface material at that location. Darker colored surfaces also tend to help accelerate snow melting and help remove the insulating effect of snow (see albedo). Snow removal on paved surfaces helps to push frost deeper by not allowing insulating snow cover to accumulate.

4.1.3.11.7. Vegetative cover: Similar to snow, vegetation acts as an insulator to slow frost penetration into the soil. Loose grasses or leaves can form insulating air pockets that reduce the depth that frost can penetrate.

4.1.3.11.8. Geographic location: In general, in Minnesota the average initial soil frost date is earlier with higher latitudes and more westerly longitudes. More northerly latitudes have longer overall frost seasons on average. In Minnesota the change in average freezing date is about 3.3 days per degree of latitude.

4.1.3.11.9. Infrastructure condition. In general, older buried infrastructure such as service lines, pipes and conduits are in a more deteriorated condition than newer infrastructure and are more susceptible to damage from deep frost.

4.1.3.12. Prevention

Unknown, pending conclusion of the Hennepin County Emergency Management assessment in 2020.

4.1.3.13. Mitigation

4.1.3.13.1. Frozen water lines. Water lines can be protected against *deep frost* by ensuring they are buried to the correct depth. Lines which are already installed can resist freezing by ensuring a constant flow of a small amount of water (pencil-diameter stream from a faucet) flowing in from the service line. Typically, water utilities will request that customers maintain running water at addresses that have had freezing problems in the past.

4.1.3.13.2. Buildings, roads and infrastructure. When it occurs, typical vertical ground movement due to frost heaves and melt collapse is between 4 to 8 inches. Extreme movement can be up to 24 inches. These ground movements are enough to cause significant damage to human-made structures. Various mitigation measures can protect structures against frost heave and melt collapse. Buildings which are heated rarely experience frost heave problems because of a portion of the heat is received by the surrounding soil which prevents ice lens formation and heave action. For unheated structures, heaves can be prevented through keeping waters out of freezing zone. Another mitigation method is to ensure soils surrounding structures are those less susceptible to frost problems.

4.1.3.13.3. Distribution pipelines. Pipelines are susceptible to frost heave-produced ground movements. Pipe materials, joining methods, soil conditions and water drainage are all important factors in prevention of damages. In areas susceptible to frost heave damage, pipeline materials should shift away from cast iron and threaded steel pipe and be replaced by plastic of welded steel. Other measures can be taken to reduce the chances of frost damage to pipelines. These include drainage to reduce water in the soil and eliminate standing water over pipelines. Soil conditions may also be modified to reduce susceptibility to ice lens formation.

4.1.3.13.4. Flooding. Deep frost penetration can worsen spring meltwater flooding by preventing soil absorption of snow melt or rainwater. Flood control and management measures must take into account the potential for deep frost effects in spring flood scenarios.

4.1.3.14. Response

Unknown, pending conclusion of the Hennepin County Emergency Management assessment in 2020.

4.1.3.15. Recovery

Unknown, pending conclusion of the Hennepin County Emergency Management assessment in 2020.

4.1.3.16. References

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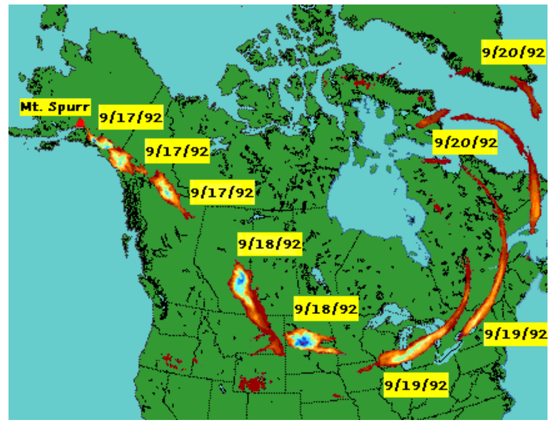
4.1.4.	Hazard Assessment: VOLCANIC ASH

4.1.4.1. Definition.

Volcanic ash consists of tiny particles of jagged rock and natural glass blasted into the air by a volcano. This ash poses threats to human and animal health, aircraft engines, electronics, machinery, electrical power generation and telecommunications. Winds may carry ash thousands of miles, impacting areas and people far away from the volcano itself. Volcanic ash is not the product of combustion, and thus is not similar to the light ashes made by burning leaves, wood, or coal, for example. Volcanic ash particles are hard rock fragments that do not dissolve in water. Ash is extremely abrasive, mildly corrosive and can conduct electricity when wet.



4.1.4.2. Range of magnitude

Unknown, pending conclusion of the Hennepin County Emergency Management assessment in 2020.

4.1.4.3. Spectrum of Consequences

4.1.4.3.1. PRIMARY CONSEQUENCES

4.1.4.3.1.1. Aircraft. Aircraft in flight are particularly vulnerable to the effects of exposure to volcanic ash. Often the ash cloud is invisible to the flight crew, and must be detected by the odor of sulfur, or by a haze developing on the windscreen. The electrically-charged ash particles can interfere with navigational and flight instruments, and communications equipment. The ash may clog the pitot-static system that indicates airspeed and feeds air to several vital flight instruments. Abrasion by the jagged particles can erode leading edge surfaces, and quickly produce a haze on windscreens so that pilots are unable to see through them. Turbine compressor blades in jet engines can wear quickly. Finally, the low melting temperature of volcanic ash means that the particles liquefy in the ignition chamber of jet engines, but quickly cool in the next engine stage and end up coating engine parts with a glaze of volcanic glass. Engines have failed from ingesting volcanic ash. Repair costs from encounters with ash can cost millions of dollars per aircraft.

4.1.4.3.1.2. Surface transportation. At the surface, ash fall could produce hazardous driving conditions by cutting visibilities when at least 1 millimeter (1/32 inch) of ash accumulates on roadways. Ash fall amounts of accumulation greater than 1 mm (1/32 Inch) also obscure markings on roadways, causing confusion among drivers in the low visibility conditions.

4.1.4.3.1.3. Human health. The main health impact of volcanic ash to people (and animals) are to the respiratory tract and to the eyes. Ash particles less than 100 nanometers in size produce upper airway irritation. Ash particles less than 10 nanometers in size are able to penetrate deep into the lung and worsen the conditions of those with various pre-existing lung diseases. Ashes with high crystalline silica content may also increase risk for suture silicosis. Technical analysis is required to determine silica component of the ash.

4.1.4.3.2. SECONDARY CONSEQUENCES:
Unknown at this distance from source volcanoes.

4.1.4.4. Potential for Cascading Effects

Volcanic ash is capable of various degrees of destruction, largely based on the distance it has traveled from the volcano of origin. Ash falling to the surface in areas near the volcano is much coarser and heavier than the ash that winds are able to carry for hundreds of thousands of miles from the eruption. Since the principle volcanic ash producing threats are located at least 800 miles west of Hennepin County, the destructive potential is restricted to the characteristics of ash that is able to be wind-transported that far. The most significant impacts at this distance involve the critical safety threat of aircraft flying through invisible high-altitude ash clouds. Sensitive electronic devices including computers, communications equipment, medical devices and other critical equipment can be damaged by the abrasive and electrically-charged particles. Finally, human and animal health impacts can occur as a result of the effect that the irritating volcanic ash has on the respiratory system and on eyes.

4.1.4.5. Geographic Scope of Hazard

Most volcanic ash is produced during explosive volcanic eruptions. Explosive volcanoes are found along the boundaries of Earth's converging tectonic plates that are converging, such as along the Pacific Rim, sometimes called the Ring of Fire. Other volcanic activity are at mantle plumes, called 'hot spots, which melt through tectonic plates. The closest volcano to Hennepin County is the Yellowstone Caldera, located about 800 miles west, in northwest Wyoming. The belt of volcanoes in the Cascade Range are about 1300 miles west of Hennepin County in eastern Washington State. Prevailing winds from the west set up Minnesota as a potential recipient of ash from volcanic eruptions in the western United States, Canada and Alaska.

4.1.4.6. Chronologic Patterns

Unknown, pending conclusion of the Hennepin County Emergency Management assessment in 2020.

4.1.4.7. Historical Data

Several major eruptions have occurred in North America where ash clouds traveled great distances. These include the **Spurr Volcano**, Alaska (27 June 1992); **Mount Saint Helens**, Washington (18 May 1980) and the **Novarupta Volcano**, Alaska (06 June 1912). Ash from the Spurr volcano traveled over Minnesota (see graphic at the beginning of this section) in September 1992.

Pre Historic Evidence

Some extremely large volcanic eruptions occurred in the geologically-recent past in the **Yellowstone Super-Volcano** complex in northwestern Wyoming. The United States Geological Survey estimates an average recurrence rate of explosive volcanic eruptions at Yellowstone to be between 600,000 and 800,000 years. The pervious explosive eruptions have been the **Lava Creek Eruption**, Yellowstone, WY (630,000 years ago); the **Mesa Falls Eruption**, Yellowstone, WY (1.3 million years ago); and the **Huckleberry Ridge Eruption**, Yellowstone, WY (2.1 million years ago). Massive ash falls were generated by these eruptions.

4.1.4.8. Future Trends

There is no evidence that typical volcanic activity levels among the volcanoes that pose an ash fall threat to Hennepin County are either increasing or decreasing. These volcanic events happen in geologic time in which eruption recurrence rates of hundreds, thousands or even hundreds of thousands of years are possible.

Event Probabilities: The United States Geological Survey (USGS) has estimated the activity level and eruption recurrence rate of each of the volcanoes in the western United States, Canada and Alaska.

4.1.4.9. Indications and Forecasting

Volcanic forecasting is the responsibility of the United States Geological Survey and its Volcano Observatories. USGS scientists categorize volcanoes and estimate their explosive potential based on evidence of past eruptions.

4.1.4.10. Detection & Warning

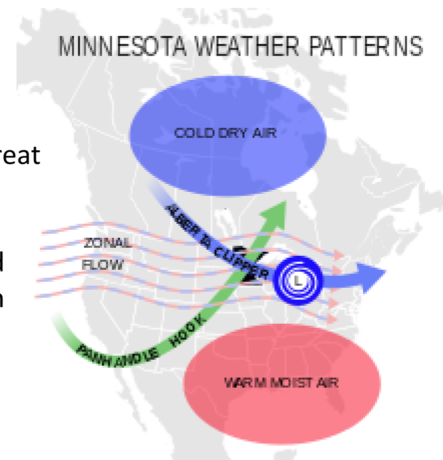
USGS scientists monitor precursor activity and are often able to issue alerts of impending eruptions months or weeks prior to the event. Ash clouds, in particular, are tracked by the National Oceanic and Atmospheric Administration. The Washington Volcano Ash Advisory Center (WVAAC) is responsible to provide alert and warning services for aviation safety. The Minneapolis Air Route Traffic Control Center (ARTCC) is served by the WVAAC.

4.1.4.11. Critical Values and Thresholds

4.1.4.11.1. Diameter: Ash particles are less than 2 millimeters in diameter down to very extremely small particles of less than 0.001 millimeter. Volcanic ash is lofted high into the atmosphere and can be blown thousands of miles away from the volcano. Larger and heavier particles will fall to Earth much more quickly than smaller and lighter particles which may remain aloft for weeks or longer. Extremely small particles suspended in the air can be invisible to the human eye, yet present hazards to aviation

4.1.4.11.2. Density: Ash particles have variable degrees of density (pumice, 700-1200 kg/m3; glass, 2350-2450 kg/m3; crystals, 2700-3300 kg/m3; and rock particles, 2600-3200 kg/m3). The high density ash particles are hard (5 Mohs scale). Window glass and steel have a Mohs hardness of 5.5, for example. Ash particles have sharp edges making them very abrasive.

4.1.4.11.3. Weight: Fallen volcanic ash is heavy and poses a risk to buildings close to the eruption, particularly those with flat roofs. A dry layer of ash 4 inches thick weighs 120 to 200 pounds per square yard, and wet ash weight is usually double the dry totals. Ash weight should not be a threat to Minnesota structures.



4.1.4.11.4. Prevailing winds. Both east-west zonal flow and Alberta Clipper systems bring winds to Minnesota from regions that host active volcanoes.

4.1.4.12. Prevention

Unknown, pending conclusion of the Hennepin County Emergency Management assessment in 2020.

4.1.4.13. Mitigation

4.1.4.13.1. Avoidance. Avoidance of flight through ash clouds is vital to aviation safety. Ash cloud alerts and warnings provide air route control centers the information they need to vector aircraft away from ash clouds.

4.1.4.13.2. Personal protection. Personal protective equipment such as filtration masks and eye protection from covered goggles are needed to avoid some of the health risks posed by volcanic ash.

4.1.4.13.3. Barriers. Sealing off rooms that have sensitive electronics can be done with plastic sheets and duct tape. Covering individual devices may also help protect them against ash.

4.1.4.14. Response

Unknown, pending conclusion of the Hennepin County Emergency Management assessment in 2020.

4.1.4.15. Recovery

Unknown, pending conclusion of the Hennepin County Emergency Management assessment in 2020.

4.1.4.16. References

4.2. Hydrological Hazards

4.2.1.	Hazard Assessment: FLOODING, URBAN

4.2.1.1. Definition

Urban flooding occurs when rain overwhelms drainage systems and waterways and makes its way into the basements, backyards, and streets of homes, businesses, and other properties. As land is converted from fields or woodlands to roads or parking lots, it loses its ability to absorb rainfall. Because of this, densely populated areas are at a high risk for flash floods. The construction of buildings, highways, driveways, and parking lots increases runoff by reducing the amount of rain absorbed by the ground.

4.2.1.2. Range of magnitude

The 10-year average of recent flood damages is about $20 billion. However, some years have run as high as $40 billion.

- Deadliest Flash Flood (Dam Collapse): 1889, Johnstown Pennsylvania : 2,200 people died
- Deadliest torrential rain flood: July 31, 1976 Big Thompson Canyon, Colorado: 143 people died
- Longest duration: 1993 61 days; The Great Midwest Flood
- Greatest USD Damage: $12 Billion 1993; The Great Midwest Flood

4.2.1.3. Spectrum of Consequences

There are several ways in which storm water can cause the flooding: overflow from rivers and streams, sewage pipe backup into buildings, seepage through building wall and floors, and the accumulation of storm water on property and in public rights-of-way. Sometimes, streams through cities and towns are routed underground into storm drains. During heavy rain, the storm drains can become overwhelmed and flood roads and buildings. Low spots, such as underpasses, underground parking garages, and basements can become dangerous.

The economic, social and environmental consequences of urban flooding can be considerable. Water quality issues can arise from sewer overflow's debris contamination, fertilizer runoff from agriculture etc.… which affect public health with possible contaminated drinking water and water borne illnesses. The cost of removal of soil from landslides, or sediment deposits from flooding can be high, as well as wildlife habitat reconstruction as wildlife habitat can be ruined by wash out, water contaminates, oxygen loss, or loss of access to food sources

Chronically wet houses are linked to an increase in respiratory problems, and insurance rates and deductibles may rise to compensate for repeated basement flooding claims. Industry experts estimate that wet basements can lower property values by 10-25 percent and are citied among the top reasons for not purchasing a home. According to FEMA, almost 40 percent of small businesses never reopen their doors following a flooding disaster. Between 2006–2010 the average commercial flood claim made to the NFIP amounted to just over $85,000. Urban flooding also erodes streams and riverbeds, and degrades the quality of our drinking water sources and the health of our aquatic ecosystems.

4.2.1.4. Potential for Cascading Effects

Structures that encroach on the floodplain, such as bridges, can increase upstream urban flooding by narrowing the width of the channel which can cause sediment and debris carried by floodwaters further because the flow is occurring at a higher stage past the obstructions. This can cause channels to become filled with sediment or become clogged with debris causing issues farther upstream from where the initial flooding occurred.

Depending on the extent of the flooding, water quality becomes an issue because it becomes necessary to treat contaminated runoff, but depending on the contaminants present this process can be very costly especially when compared to its benefits. In addition to water quality in the runoff poses issues, if any sewer or water treatment plants have been flooded, homes may now not have access to clean water or working restrooms.

4.2.1.5. Geographic Scope of Hazard

The extent of urban flooding in Hennepin County really depends on an extremely complex set of interactions between the surface and sub-surface drainage networks and features of the environment. Urban flooding can be small in geographic scope as in just a few streets or neighborhoods with minor flooding damage, to large areas of entire cities being under water.

4.2.1.6. Chronologic Patterns

Urban flooding in Hennepin County typically occurs in the spring and summer months associated with thunderstorms. Springtime urban flooding can come from both snowfall melt and runoff during the spring, a spring thunderstorm that comes before the ground has had time to that completely preventing infiltration, or just a normal thunderstorm (or multiple thunderstorms within a smaller period of time) with excessive rainfall rates.

4.2.1.7. Historical Data

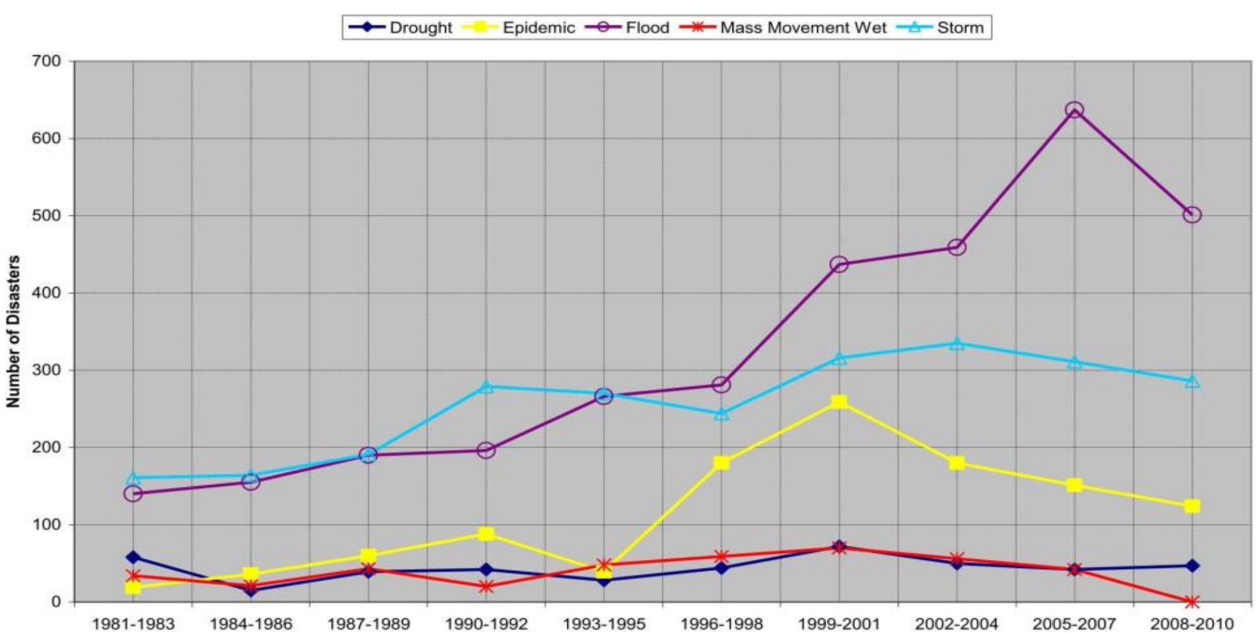
Floods have been documented all the way back to 1776 in Minnesota. However official American records don’t begin until 1873. As mentioned in river flooding, of the 24 State of Minnesota Flood Declarations, Hennepin County has been included in six, with all having urban flooding issues with road and bridge closures.

- 1965 Flooding (DR-188)
- 1969 Flooding (DR-255)
- 1997 Severe Flooding, High Winds, Severe Storms (DR-1175)
- 2001 Severe Winter Storms, Flooding, and Tornadoes (DR-1370)
- 2010 Flooding (DR-3310)
- 2014 Severe Storms, Straight-Line Winds, Flooding, Landslides and Mudslides (DR-4182)
- 2016 Severe Storms & Flooding (DR-4290)

4.2.1.8. Future Trends

Urban flooding is a naturally-occurring hazard that affects cities and regions around the world, and is expected to become even more problematic in the future. Damages from floods are also increasing as are the number of people who are affected by them.

Human-induced land cover change and climate change are important factors in urban flooding. Rapid population growth and increasing migration from rural areas to cities lead to intense urbanization, which often increases flood risk. According to recent studies, the urban heat island effect and aerosol composition can alter the climate mechanism, which plays an important role in the storm evolution of urbanized regions. Global warming, the other main cause of hydrologic regime change, can induce the acceleration of the water cycle, which can consequently affects the frequency and intensity of future storm events. Research has shown that in the future we may not necessarily see more rainfall, but more rainfall on less days. That is to say that if the monthly average total rainfall is four inches over eight different days, we would now see that four inches come on three or four days. So same amount of rain, just coming more at one time.



4.2.1.9. Indications and Forecasting

Currently, the operational method for forecasting flash floods at the National Weather service is to utilize the Flash Flood Monitoring and Prediction software package to compare rainfall estimates with flood-induced rainfall accumulation thresholds, known as flash flood guidance values. The success of this guidance depends on both accuracy of radar-estimated rainfall rates and the flash-flood guidance values. The National Weather Service Weather Forecast Offices issues all flash-flood advisories, watches, and warnings for their respective county warning areas. The primary indicator used by forecasters to predict onset of flash flooding, is when radar-based rainfall estimates exceed flash flood guidance values over f 1, 3, or 6 hours. Flash-flood guidance is define as the threshold rainfall required to initiate flooding on small streams that respond to rainfall within a few hours.

4.2.1.10. Detection & Warning

The National Weather Service issues flash flood advisories, watches and warnings.

- ***Flood Advisory***: Thunderstorms have produced heavy rainfall that may result in ponding of water on roadways and in low-lying areas, as well as rises in small stream levels, none of which pose an immediate threat to life and property.
- ***Flash Flood Watch***: Atmospheric and hydrologic conditions are favorable for short duration flash flooding and/or dam break is possible.
- ***Flash Flood Warning***: Excessive rainfall producing thunderstorms have developed, lead to short duration flash flooding. A warning may also be issued if a dam break has occurred.

4.2.1.11. Critical Values and Thresholds

Using thresholds for flooding indicators can be intellectual traps for the uneducated and what constitutes an important threshold in one situation may be unimportant in another. In broad terms, moderately high rainfall rates begin at about 1 inch per hour, and moderately long durations begin at about one hour, but these should be considered only as the crudest of guidelines.

Conversation with the local National Weather Service in Chanhassen, MN has concluded that local forecasters tend to look at the rainfall rate and return period more than any particular amount threshold. It also depends on antecedent conditions. Consensus between the hydrologist and an operation warning forecaster is they look for model outputs to show them at least a 10-year event as a starting point to actually get flash flooding. In addition, using one particular source, they use a return period for precipitation to have at least a 20-50 year event to get flash urban flooding in the Twin Cities Metro area.

4.2.1.12. Prevention

To improve water management and protect the sewage system from damage, cities can revamp their underground pipe and drainage systems by separating rainwater from the sewage system. The separation enables the wastewater treatment plant to function properly, without it being overburdened by large quantities of storm water.

Other more obvious methods are to keep sewer systems clean of clog up with waste, debris, sediment, tree roots and leaves.

4.2.1.13. Mitigation

Areas that have been identified as flood prone areas can be turned into parks, or playgrounds, buildings and bridges can be lifted, floodwalls and levees, drainage systems, permeable pavement, soil amendments, and reducing impermeable surfaces. Reducing impervious surfaces could include the addition of green roofs, rain gardens, grass paver parking lots, or infiltration trenches.

Other mitigation strategies include developing a floodplain management plan, form partnerships to support floodplain management, limit or restrict development in floodplain areas, adopt and enforce building codes and development standards, improve storm water management planning, adopt policies to reduce storm water runoff, and improve the flood risk assessment.

4.2.1.14. Response

One of the most important things to be done during the initial response is to make sure that people are safe. If their homes have been damages and are unlivable, finding a place for them to stay is among one of the top priorities. Next is the access to places if roads are washed out or still underwater. One complicated factor with flood disasters, is sometimes you do not know how bad the damage is until the water recedes, which can take time and slow the response. Another important part of response is to make sure water supply is available as quick as possible if there has been any contamination. The role of Hennepin County Emergency Management is to coordinate resources that our municipalities may need to accomplish all response needs.

4.2.1.15. Recovery

As mentioned in river flooding, recovery from floods can take weeks, to months, to years. Urban flooding, is unlike quick disasters (e.g. tornadoes) where you can see the damage immediately, sometimes with urban flooding you have to wait for the flood waters to recede to find out what damage there is to recover from. A lot of the time, the longer the water level stays too high, the more consequences are introduced that you have to then recover from.

4.2.1.16. References

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4.2.2.	Hazard Assessment: FLOODING, RIVER

4.2.2.1. Definition

River flooding occurs when river levels rise and overflow their banks or the edges of their main channel and inundate areas that are normally dry. River flooding can occur from both flash flooding event (high precipitation) and/or ice/snow melt in the spring. The amount of flooding is usually a function of the amount of precipitation in an area, the amount of time it takes for rainfall to accumulate, previous saturation of local soils, and the terrain around the river system, dam failures, rapid snowmelt and ice jams. Over 750 of Presidential Disaster Declarations result from flooding.

River flooding is classified as Minor, Moderate, or Major based on water height and impacts along the river that have been coordinated with the National Weather Service. Minor river flooding means that low-lying areas adjacent to the stream or river, mainly rural areas and farmland and secondary roadways near the river flood. Moderate flooding means water levels rise high enough to impact homes and businesses near the river and some evacuations may be needed. Larger roads and highways may also be impacted. Major flooding means that extensive rural and/or urban flooding is expected. Towns may become isolated and major traffic routes may be flooded.

4.2.2.2. Range of Magnitude

- United States
    - Most destructive flood: Mississippi River, 1927 (500 killed; 600,000 homeless)
    - Costliest Flood: Great Mississippi & Missouri River Flood of 1993 ($30.2 billion)

- Minnesota
    - Most destructive flood: 1997 Red River Flood (58 of 87 counties in Minnesota Federally Declared Disasters)
    - MN costliest flood: 1997 Red River Flood ($2 billion)

4.2.2.3. Spectrum of Consequences

River flooding can affect both people and property. Losses in both wildlife and livestock can also occur, which can drastically affect the economy. In addition, road washouts, power and water outages can also be common with river flooding.

4.2.2.4. Potential for Cascading Effects

There is high potential for cascading consequences from river flooding. Depending on the severity of the flooding, there could be public health sanitation problems, landslides, food spoilage and food production shortages from farmland being underwater.

4.2.2.5. Geographic Scope of Hazard

River flooding occurs across all of Hennepin County. Three major rivers create Hennepin County borders on the northwest, south and east side. Those include the Minnesota, Crow and Mississippi Rivers. In addition, several creeks and streams across Hennepin County have a history of flooding, which have caused damage to property. Some of those include the Minnehaha Creek, and Nine Mile Creek. All of these rivers and creeks are susceptible to early spring snow-melt flooding as well as summer and fall storm seasons.

4.2.2.6. Chronologic Patterns

River flooding can occur because of both snowmelt and high precipitation events which makes the flood season start from early spring to early winter. It of course depends on how warm we start to get in the spring how early, to when we start to get below freezing in the winter. For example, if there is more than average snowfall/snow depth tied together a spike in temperatures during the early spring, we are melting snow without having a fully thawed out ground, making soil impervious, which increases the runoff and subsequently increasing chances for flooding.

4.2.2.7. Historical Data/Previous Occurrence

Floods have been documented all the way back to 1776 in Minnesota. However official American records don't begin until 1873. Minnesota has seen twenty-four Disaster Declarations due to flooding, six of which have been in Hennepin County.

1965 Flooding (DR-188)

- The Mississippi River at Fridley crested at 20 ft. on April 17th, 1965 which was 4 ft. over flood stage.
- On April 15, the Minnesota River at Savage crested at 719.40 ft., over 17 ft. above flood stage (702 ft.), and 7 ft. above major flood stage (712 ft.). A day later on April 16th, the Mississippi river at St Paul crested at 26.01 ft., 12 ft. above flood stage (14 ft.) and 9 ft. above major flood stage (17 ft.). The St Croix River at Stillwater followed suit with a record crest of 94.10 ft. on April 18, is 7 ft. above flood stage (87 ft.) and 5 ft. above major flood stage (89 ft.).

1969 Flooding (DR-255)

- The Mississippi River at Fridley crested at 17.50 ft. on April 14, 1969, which was 1.5 ft. over flood stage.

- Crow River crested at 16.5 ft. on April 11, 1969, which is 6.5 ft. over flood stage.

1997 Severe Flooding, High Winds, Severe Storms (DR-1175)

- The Mississippi River at Fridley crested at 17.10 ft. on April 10, 1997 which is 1.1 ft. over flood stage.
- Crow River reached flood stage of 10 feet on 4/4/97 at Rockford which is the river monitoring point. The river crested at 14.4 feet on 4/9/97 which was the fifth highest crest ever recorded. The river subsided to below flood stage on 4/20/97. Substantial flooding occurred at a golf course in the town of St. Michael. (NCDC Storm Events)

2001 Severe Winter Storms, Flooding, and Tornadoes (DR-1370)

- The Mississippi River at Fridley crested twice. First at 16.60 ft. on April 15, 2001 and second at 16.40 ft. on April 28th 2001, 0.6 and 0.4 ft. over flood stage respectively.
- Four factors contributed to the flooding of 2001: significant autumn precipitation, heavy winter snowfall, less than ideal snowmelt scenario, and record breaking April precipitation (http://climate.umn.edu/doc/journal/flood_2001/flood_2001.htm). April 16th the Crow River at Rockford, MN crested at 14.5 feet with a peak discharge at 13,100 ft3/s which is 4.5 ft. over flood stage.

2010 Flooding (DR-3310)

- Crow River at Rockford reached 13.99 ft. on March 22, 2010,which was 3.99 ft. over flood stage.

2014 Severe Storms, Straight-Line Winds, Flooding, Landslides and Mudslides (DR-4182)

- Crow River at Rockford crested at 15.08 ft. on June 25th, 2014, which was 5.08 over flood stage.

4.2.2.8. Future Trends

Changes in river flooding can be caused by changes in atmospheric conditions, land use/land cover, and water management. These changes can occur in tandem, or individually which makes it difficult to determine which factor acts as the driving force of changes in river flooding behavior. However, long-term data does show and increase in flooding in the norther half of the eastern prairies and parts of the Midwest. Even with data showing days with heavy precipitation increasing, this trend does not strongly related to changes, or increases, in river flooding. One conclusion for this is the mismatch of seasons with which the high precipitation events occur and most likely season for flooding in most river basins within our region[8]. For example, the northern Great Plains typically sees peak river flooding during spring snowmelt, however, generally the heaviest daily rainfall events occur during the summer.

When considering the issue of future river flood hazard changes, it is important to recognize that urban and rural land-use impacts and water management have significant influence on river flood behavior.

While precipitation and flooding have been increasing in the northern half of the eastern prairies, general circulation models do not show this as an area expected to have a substantial increase in runoff in the twentieth-century or the twenty-first century forecast.

4.2.2.9. Indications and Forecasting

River Flooding typically occurs hours to days after a high precipitation event. Warnings for river floods can often provide much more lead-time that those for flash flooding.

4.2.2.10. Detection & Warning

The National Weather Service issues flood advisories, watches and warnings[16].

- ***Flood Advisory*:** Thunderstorms have produced heavy rainfall that may result in ponding of water on roadways and in low-lying areas, as well as rises in small stream levels, none of which pose an immediate threat to life and property.
- ***Flood Watch*:** Atmospheric and Hydrologic conditions are favorable for long duration areal or river flooding
- ***Flood Warning*:** Long duration areal or river flooding is occurring or is imminent, which may result from excessive rainfall, rapid snow met, ice jams on rivers or other similar causes.

4.2.2.11. Critical Values and Thresholds

The National Weather Service uses flood categories to communicate/categorize the severity of flood impacts in the corresponding river/stream reach. The severity of flooding at a given stage is not necessarily the same at all locations along a river reach due to varying channel/bank characteristics or presence of levees on portions of the reach. Therefore, the upper and lower stages for a given flood category are usually associated with water levels corresponding to the most significant flood impacts somewhere in the reach.

The flood categories used by the National Weather Service are:

- ***Minor Flooding*** - minimal or no property damage, but possibly some public threat (e.g., inundation of roads).
- ***Moderate Flooding*** - some inundation of structures and roads near stream. Some evacuations of people and/or transfer of property to higher elevations.
- ***Major Flooding*** - extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations.
- ***Record Flooding*** - flooding which equals or exceeds the highest stage or discharge observed at a given site during the period of record. The highest stage on record is not necessarily above the other three flood categories, it may be within any of them or even less than the lowest, particularly if the period of record is short (e.g., a few years). It is also important to note that minor, moderate, major flood categories do not necessarily exist for all forecast points. For

example, a location with a permanent levee may begin to experience impacts at moderate flooding level.

4.2.2.12. Prevention

The majority of prevention methods of river flooding fall under mitigation actions. See Mitigation below for methods of prevention.

4.2.2.13. Mitigation

There are many different ways to mitigate flooding hazards. Two techniques are hard and soft engineering mitigation techniques. Hard engineering techniques include building dams, levees, wing dykes, and diversion spillways. Soft engineering techniques include floodplain zoning, afforestation, wet plain restoration, river restoration, and removal of properties in flood prone areas.

4.2.2.14. Response

- Hennepin County Emergency Management Capabilities
- Situation monitoring Station (SMS)
- Immediate Impact Reconnaissance Teams
- Hennepin County Emergency Operations Plan

4.2.2.15. Recovery

Recovery from floods can take weeks to months to years. One complicating factor when it comes to river flooding, is unlike quick disasters (e.g. tornadoes) where you can see the damage immediately, river flooding you have to wait for the floodwaters to recede to find out what damage there is to recover from. A lot of the time, the longer the water level stays too high, the more consequences are introduced that you have to then recover from.

4.2.2.16. References

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4.3. Meteorological Hazards

4.3.1.	Hazard Assessment: CLIMATE CHANGE

4.3.1.1. Definition

Minnesota experiences extremes of both temperature and precipitation occurring days, weeks months, and years because of its location in the interior of North America. The polar jet stream is often located near or over the region during the winter, which brings cloudy skies, windy conditions, and precipitation. During the spring and early summer, the jet retreats northward creating an atmosphere compatible for of severe thunderstorms and tornadoes.

Climate change is a significant and ongoing change in the long-term statistical and or spatial behavior of weather patterns and variables. In the 21st century, the leading driver of climate change is the increase in global average temperatures, in response to the intensified combustion of fossil fuels and deforestation. The increasing global temperatures have triggered a series of responses in the earth system that have modified the patterns of global atmospheric circulation.

4.3.1.2. Range of Magnitude

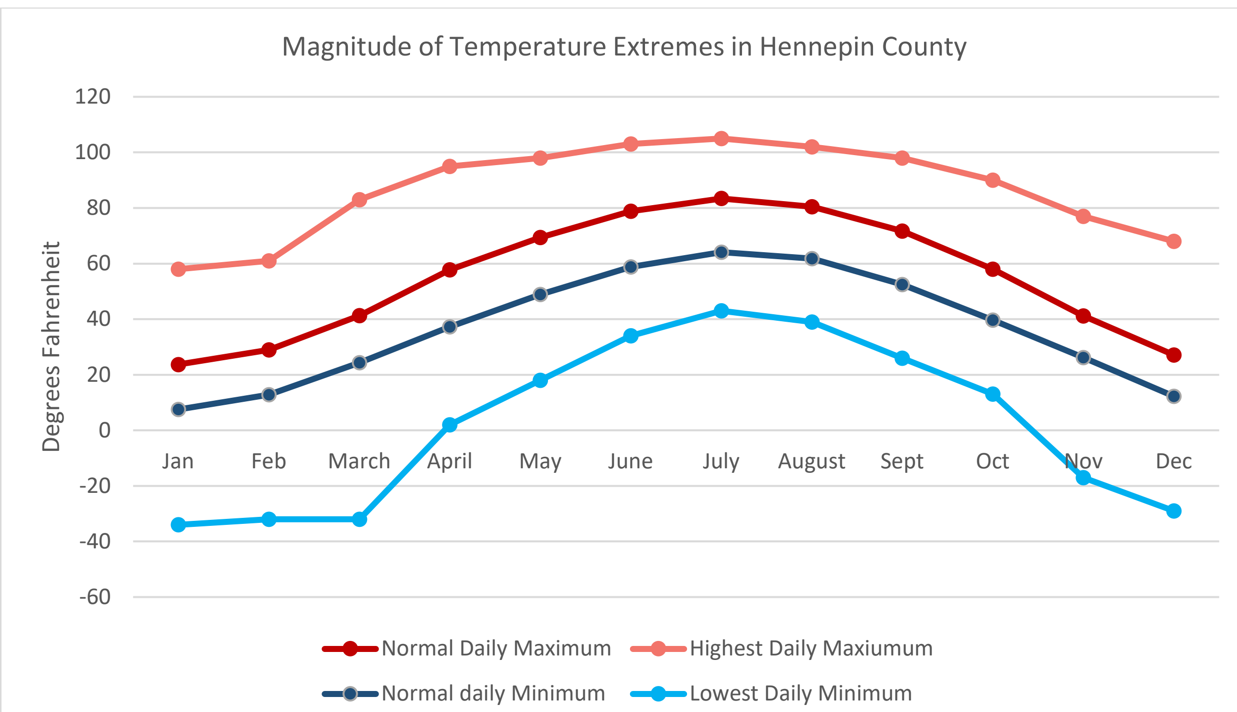
When looking at climate change, much of the time extremes are noted as example of how the climate is changing. The table below shows monthly normal and extremes (with year occurred) of precipitation amount and high and low temperatures. See **TABLE 4.3.1A and GRAPHICS 4.3.1A and 4.3.1B** for visual representation of the timeline.

TABLE 4.3.1A Monthly measurements

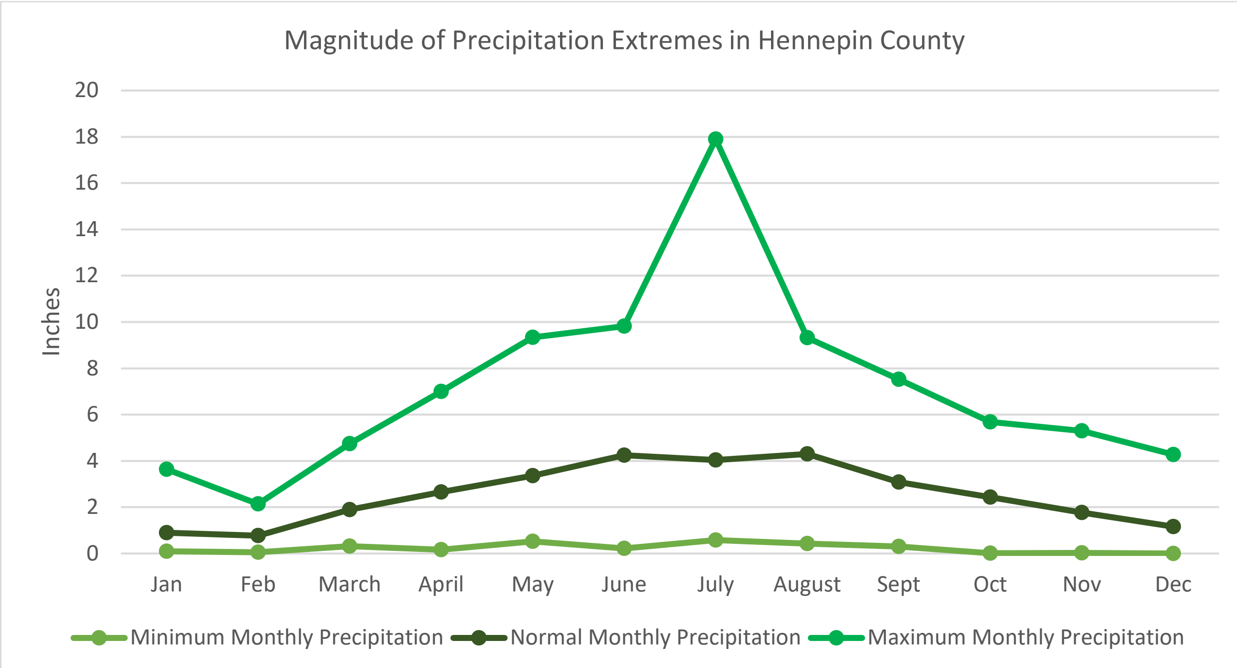
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Normal Daily Temp Max	23.7	28.9	41.3	57.8	69.4	78.8	83.4	80.5	71.7	58	41.2	27.1
Highest Daily Temp Max	58 (1944)	61 (2000)	83 (1986)	95 (1980)	98 (2013)	103 (2011)	105 (1988)	102 (1947)	98 (1976)	90 (1997)	77 (1999)	68 (1998)

Normal Daily Temp Min	7.5	12.8	24.3	37.2	48.9	58.8	64.1	61.8	52.4	39.7	26.2	12.3
Lowest Daily Temp Min	-34 (1970)	-32 (1996)	-32 (1962)	2 (1962)	18 (1967)	34 (1945)	43 (1972)	39 (1967)	26 (1974)	13 (1997)	-17 (1964)	-29 (1983)
Normal Monthly Precip	0.9	0.77	1.89	2.66	3.36	4.25	4.04	4.3	3.08	2.43	1.77	1.16
Max Monthly Precip	3.63 (1967)	2.14 (1981)	4.75 (1965)	7 (2001)	9.34 (2012)	9.82 (1990)	17.9 (1987)	9.32 (2007)	7.53 (1942)	5.68 (1971)	5.29 (1991)	4.27 (1982)
Min Monthly Precip	0.1 (1990)	0.06 (1964)	0.32 (1994)	0.16 (1987)	0.53 (2009)	0.22 (1988)	0.58 (1975)	0.43 (1946)	0.3 (2012)	0.01 (1952)	0.02 (1939)	Trace (1943)

GRAPHIC 4.3.1A Temperature Extremes



GRAPHIC 4.3.1B Precipitation Extremes



TABLES 4.3.1B- 4.3.1E shows earliest 1-inch snowfall, earliest 1-inch snow depth, latest 1-inch snowfall, and latest 1-inch snow depth.

TABLE 4.3.1B

Earliest 1-inch snowfall		
	Date	Season
1.	September 26, 1942	(1942-1943)
2.	October 10, 1977	(1977-1978)
3.	October 12, 1959	(1959-1960)
4.	October 12, 1969	(1969-1970) Tie
5.	October 12, 2009	(2009-2010) Tie
6.	October 18, 1925	(1925-1926)
7.	October 18, 1976	(1976-1977) Tie
8.	October 19, 1916	(1916-1917)
9.	October 23, 1938	(1938-1939)
10.	October 27, 1919	(1919-1920)

TABLE 4.3.1C

Earliest 1-inch snow depth		
	Date	Season
1.	October 13, 1959	(1959-1960)
1.	October 13, 1969	(1969-1970) Tie
3.	October 19, 1916	(1916-1917)
4.	October 22, 1925	(1925-1926)
5.	October 23, 1938	(1938-1939)
6.	October 25, 1905	(1905-1906)
7.	October 27, 1919	(1919-1920)
8.	October 29, 1913	(1913-1914)
9.	October 29, 1929	(1929-1930) Tie
10.	October 30, 1955	(1955-1956)

TABLE 4.3.1D

Latest 1-inch snowfall		
	Date	Season
1	January 21, 2005	(1959-1960)
2	January 9, 1945	(1969-1970) Tie
3	January 6, 1981	(1916-1917)
4	January 1, 1914	(1925-1926)
5.	December 30, 1918	(1918-1919)
6.	December 26, 1904	(1904-1905)
7.	December 21, 1920	(1920-1921)
8.	December 21, 2006	(2006-2007) Tie
9.	December 20, 1998	(1998-1999)
10.	December 19, 1939	(1939-1940)

TABLE 4.3.1E

Latest 1-inch snow depth		
	Date	Season
1	January 1, 1913	(1912-1913)
2	December 27, 1918	(1918-1919)
3	December 26, 1904	(1904-1905)
4	December 24, 1960	(1960-1961)
5.	December 22, 2006	(2006-2007)
6.	December 21, 1920	(1920-1921)
7.	December 20, 1914	(1914-1915)
8.	December 20, 1998	(1998-1999) Tie
9.	December 19, 1939	(1939-1940)
10.	December 19, 1999	(1999-2000) Tie

TABLE 4.3.1F is the magnitude of average temperature trend (°F per decade), in Hennepin County.

Season	1895-2015	1970-2015
• Annual	+0.30	+0.65
• Spring (Mar-May)	+0.33	+0.39
• Summer (Jun-Aug)	+0.32	+0.35
• Fall (Sep-Nov)	+0.2	+0.78
• Winter (Dec-Feb)	+0.34	+0.95

- Warmest year on record (since 1895):
  - 2012; 50.8° F, 6.0° F above 1901-2000 average.
- Warmest summer:
  - 1988; 76.0° F, 5.7° F above 1901-2000 average.
- Warmest winter:
  - 2001-02, 26.9° F, 10.5° F above 1901-2000 average.

4.3.1.3. Spectrum of Consequences

Evidence of observed climate change impacts is strongest and most comprehensive for natural systems. Climate models project that a warming planet could lead to changes in the distribution of precipitation across the country, including a trend toward more frequent intense-precipitation events. In urban areas, climate change is projected to increase risks for people, assets, economies, and ecosystems including risks from heat stress, storms, and extreme precipitation, flooding, landslides, air pollution, drought, and water scarcity. A 2013 study concluded that, with a warming globe, more atmospheric moisture will be available for storm systems. As a result, rainfall during extreme events is likely to become even heavier than it is now. These changes may translate into greater storm water run-off in the future, which could exacerbate flooding hazards. The U.S. National Climate Assessment also lists that increased heat wave intensity and frequency are possible, degraded air quality, reduced water quality, and more flooding events will increase public health risks with climate change.

It is very difficult, if not impossible, to link a particular event to climate change. However, certain events appear to become more likely as a result of the changing climate. The following are some consequences expected with climate change in Hennepin County:

- Less reliable and more dangerous lake ice
- More periods of bare/snow-free ground, allowing frost to penetrate to great depths during cold outbreaks
- Expansion of the heavy rainfall season, leading to enhanced peak stream flows, and altered timing of normal flow regimes
- Increased runoff and flash-flooding as the largest events intensify and become more common
- Water infrastructure damage from intense rainfall events
- Agricultural stress, from shifting crop ranges, heat, drought, extreme rainfall
- More days with high water vapor content and heat index values
- Greater summer cooling costs, more days requiring cooling
- New invasive species, both terrestrial and aquatic, especially those acclimated to warmer climates or those that were cold weather limited.
- "Hyper-seasonality," as warm conditions develop during the "off-season," leading to bouts of heavy rainfall or severe weather, followed by wintry conditions.
- Increase in frequency of freeze-thaw cycles, as winter is increasingly infiltrated by warm conditions.

Some positive benefits of a changing climate might include fewer automobile accidents and damage as more winter precipitation falls in the form of rain rather than snow or ice. However, warmer winters doesn't necessarily mean rain instead of snow, it could mean more ice storms, which would lead to dangerous driving conditions and power outages due to down power lines. Increased drought is also possible, which also brings increased associated fires, decreased agriculture output, and other environmental impacts with drought (see drought section of risk assessment).

4.3.1.4. Potential for cascading effects

More frequent intense precipitation events may translate into more frequent flash-flooding episodes. More intense heat waves may mean more heat-related illnesses, droughts, and wildfires. Please visit each individual hazard to read more about cascading effects to that specific hazard.

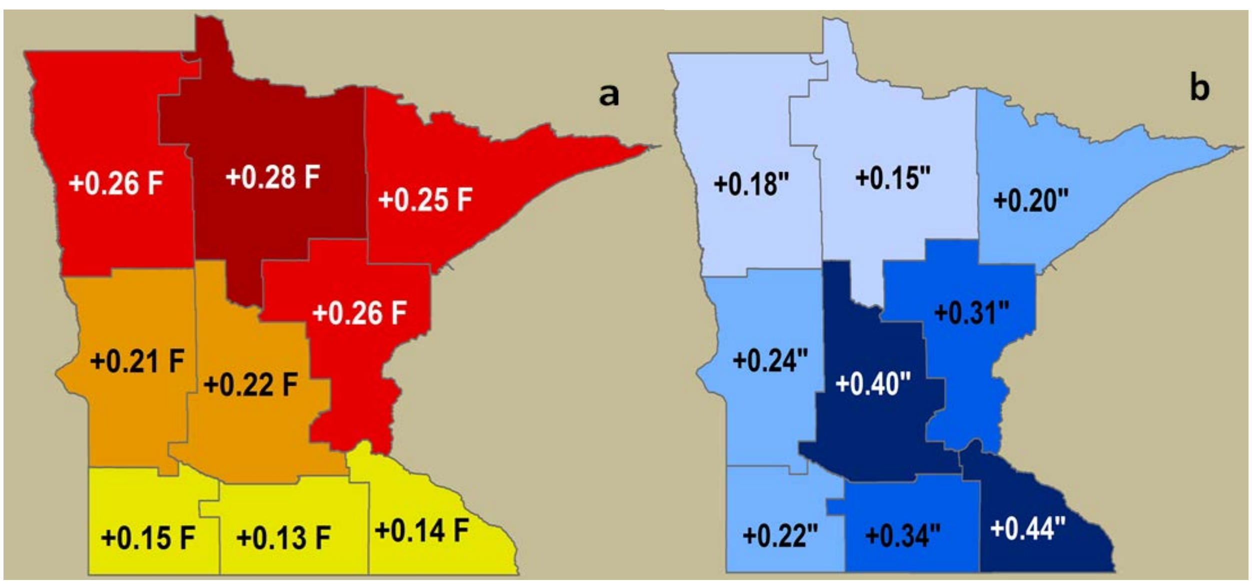
4.3.1.5. Geographic scope of hazard

The current climate of the Midwest is governed by latitude, continental location, and large scale circulation patterns. Day to day and week-to-week weather patterns are controlled generally by the position and configuration of the polar jet stream in the winter and transition seasons, with somewhat less influence in the summer months.

Climate Change affects the entire North American continent, although the high latitude and continental (interior) regions have seen the most rapid increases in temperatures. Rainfall has increased the most in areas already prone to wet regimes, and it has decreases in areas prone to dryness. Thus, as indicated by the most recent Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), we are witnessing the polarization of hydrologic regimes, with some areas becoming wetter, even as deserts expand.

In Minnesota, the greatest warming has been in the northern part of the state, and the largest precipitation increases have been in the southeastern and central portions of the state (see **GRAPHIC 4.3.1C**).

GRAPHIC 4.3.1C a) Average annual temperature change per decade, 1895-2015, by climate division. b) Same as a) but for precipitation. Maps were created in using divisional data from NOAA's *Climate at a Glance* tool.



4.3.1.6. Chronological patters (seasons, cycles, rhythm)

Warming is occurring year-round, though the most pronounced changes have been during winter. It should be noted that the area's climate exhibits natural high variability, and that variability will continue, even as Minnesota warms.

4.3.1.7. Historical Data/Previous Occurrence

The year 2012 may be thought of as a preview of the years and decades ahead. The 2011-12 winter was warm and short, with bouts of 50s and 60s observed throughout Minnesota during January. March that year saw 8 record high temperatures in Minneapolis, and 8 days above 70 degrees. Throughout the region, March 2012 obliterated long-standing daily and monthly temperature records.

The warmth continued through the remainder of the spring and into the summer, with over 30 days above 90 degrees in parts of Hennepin County, and 2 days above 100 at MSP. This was the first summer with multiple 100-degree readings since the summer of 1988.

Based on the Midwest chapter from the *2014 National Climate Assessment*, a review of other recent research into the region, and analyses of quality-controlled, nationally-standardized and publicly-available data, the recent trends can be described as follows.

- Bouts of extreme cold in Hennepin County and throughout Minnesota and the region are now at an all-time low in terms of both frequency and severity. Off all changes, the loss of cold weather extremes has the strongest link with climate change.
- Extreme rainfall episodes have become both more intense and more frequent, and Minnesota has seen five of its 12 documented "mega-rainfall" events since the year 2000. Changes in extreme rainfall behaviors are strongly linked to climate change.
- A general increase in annual and seasonal snowfall has been punctuated by an uptick in the size and frequency of large snowfall events. This is likely related to the presence of warmer air and more water vapor during winter, which provides more energy to passing low pressure systems capable of producing snow.
- Severe thunderstorms and tornadoes pose challenges to long-term analyses because of changes in reporting procedures and detection technologies over time. That said, Minnesota has been in a pronounced severe weather lull since the summer of 2011, which followed a very active spring and record-setting year for tornadoes in 2010. Confidence in the link between climate change and observed severe weather trends is low.
- Heat waves and drought have shown no increase in Minnesota in recent years and decades. The summer of 1988 was the hottest on record for Minnesota, and it was remarkably dry too. In terms of persistence, however, even 1988 cannot compare with the heat waves and droughts of the 1930s, and all recent daily summer high temperature readings are well within bounds of variability established by that exceptionally hot and dry period.

GRAPHIC 4.3.1D summarizes the scientific confidence that climate change is influencing the behavior of typical weather/climate hazards in Minnesota.

GRAPHIC 4.3.1D

Strength of *current* impact from climate change

Highest	High	Moderately High	Moderately Low	Low	Lowest

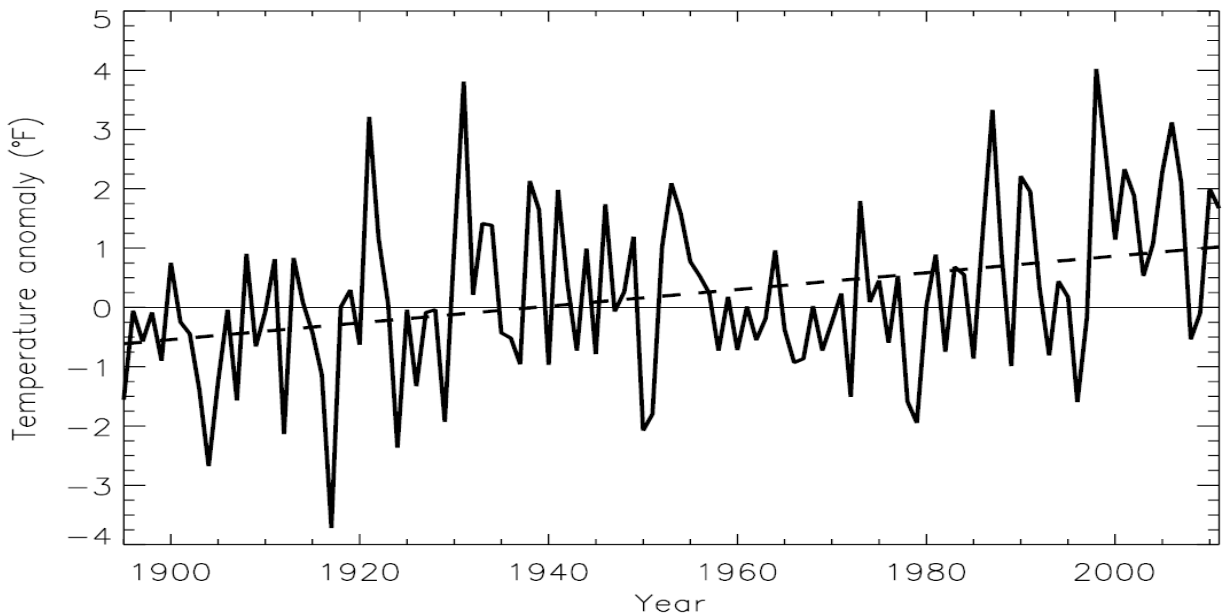
Hazard	Recent & Current Observations
Extreme cold	Rapid decline in severity, frequency
Extreme rainfall	Becoming larger and more frequent
Heavy snowfall	Large events more frequent
Severe thunderstorms & tornadoes	Long-term comparisons difficult; recent lull, but unprecedented activity in 2010
Heat waves	No recent increases
Drought	No recent increases

The following historical climate trends were pulled from the Regional Climate Trends and Scenarios for the U.S. National climate Assessment from the U.S. Department of Commerce. The data sets used to examine trends were obtained from the National Center for Environmental Information based on NWS Cooperative Observer Network observations. An additional dataset was used for temperature: East Anglia Climate Research Unit was used to examine trends in temperature.

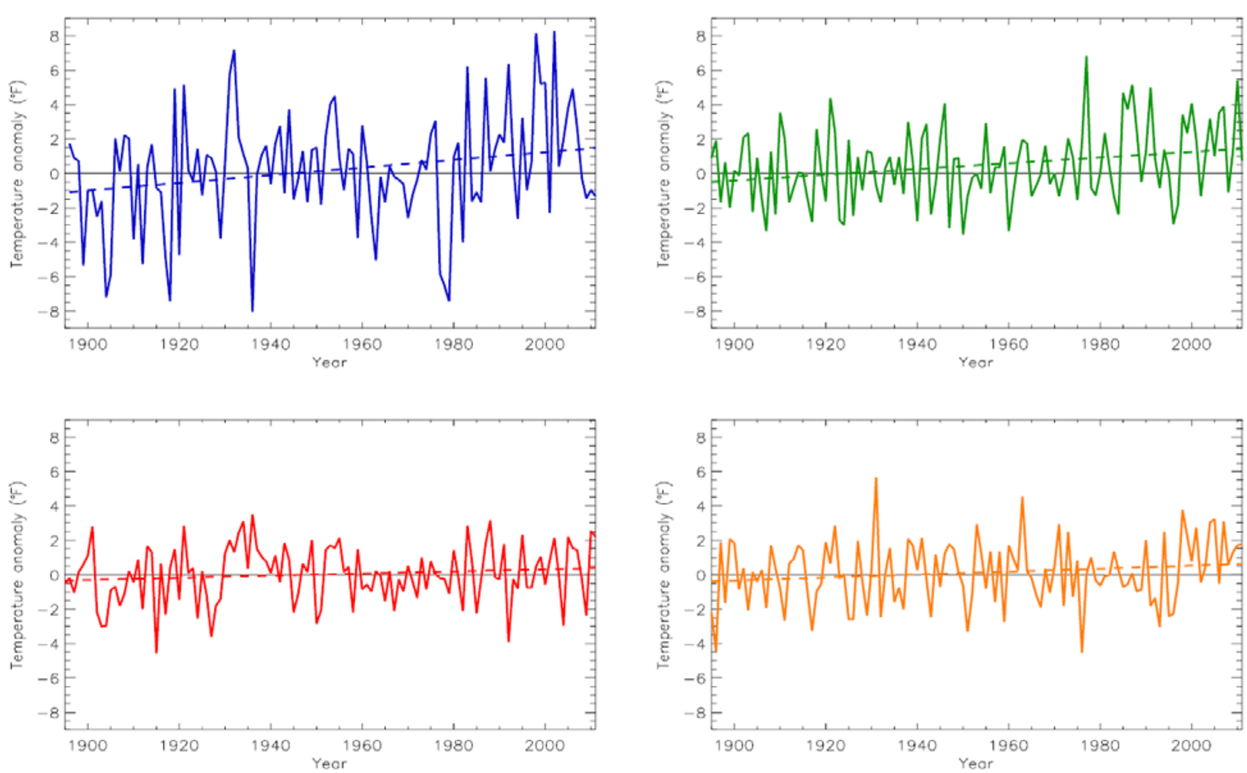
Temperature

Large inter-annual variability occurs in regional temperatures, however, historical tendencies for the Midwest region as a whole are towards increased annual temperatures. When the trend is calculated over the period of 1950-2010 it shows an increase of 0.22 oF per decade, and 0.47oF per decade for the period of 1979-2010. While temperatures have tended to be warmer than normal on the annual basis, seasonal trends vary. Refer to **GRAPHIC 4.3.1E** and **GRAPHIC 4.3.1F** for temperature anomalies (deviations from the 1901-1960 average) for the entire year and by each season. You can see that during the summer months, based on maximum temperatures, the period since the 1930s has been generally cooler. This is also seen in the mean summer temperatures. You also see that very cold winters have been infrequent in the last 20 years while several winters were much warning than average.

GRAPHIC 4.3.1E

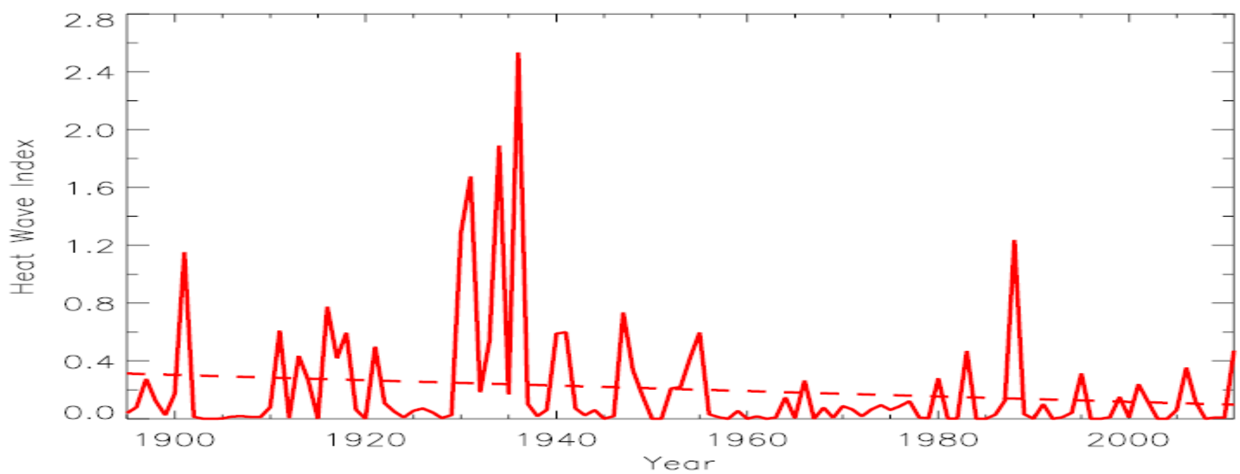


GRAPHIC 4.3.1F

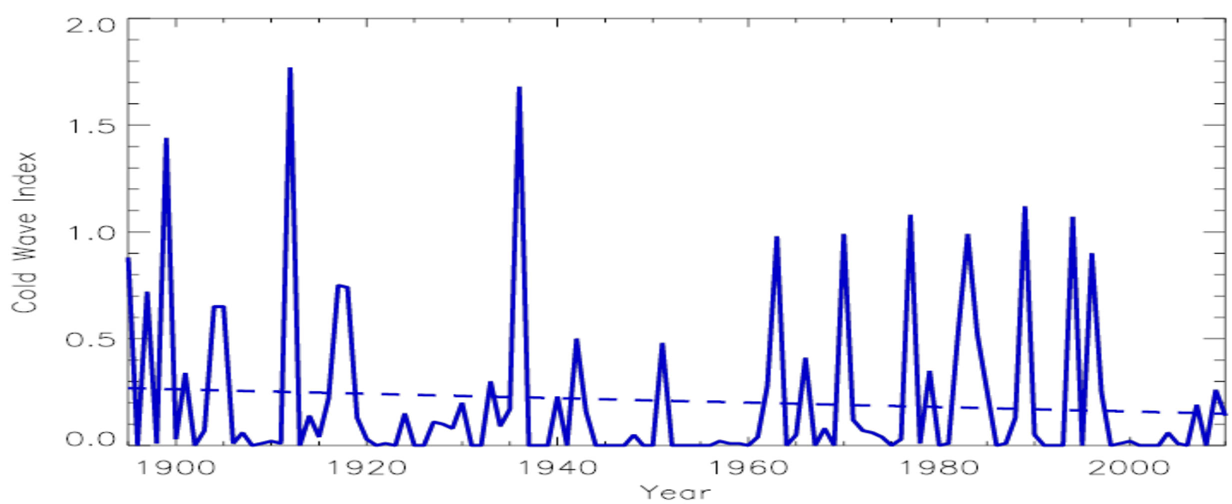


In addition to annual average temperatures, one can also look at the history of extreme warm and cold events. **GRAPHIC 4.3.1G** and **GRAPHIC 4.3.1H** show time series of an index intended to recent heat and cold events. The index reflects the number of four day duration episodes that exceed a threshold for a 1 in 5 year recurrence interval calculated from the COOP data from long term stations. You will notice the frequency of intense heat waves have not been particularly high in recent decades. In the Midwest, the heat that occurred during the 1930s remains the most intense in the historical period on record. You will also notice, the frequency of intense cold waves has also been very low since the mid-1990s, however, there is no statistically significant trend.

GRAPHIC 4.3.1G



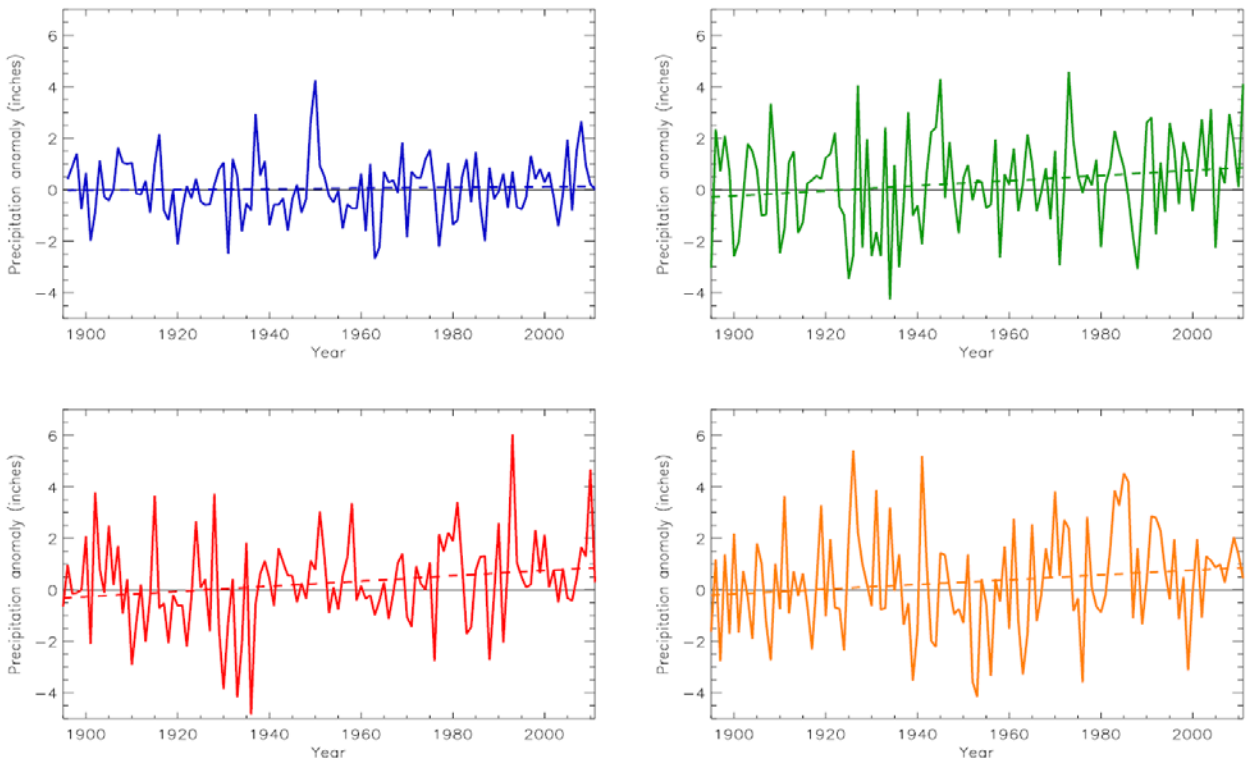
GRAPHIC 4.3.1H



Precipitation

Annual precipitation has been near or above the 1901-1960 mean in more years during the ast 40, in fact, there have been no years with major precipitation deficiencies during the last 20 years. Most of the increase in precipitation has occurred during the warm seasons, spring and summer, and account for over 90% of the increase in the overall precipitation. Refer to **GRAPHIC 4.3.1I** and **GRAPHIC 4.3.1J** for the precipitation anomalies for the entire year as well as each season individually.

GRAPHIC 4.3.1J



Climate change also affects the economy. According to the Insurance Federation of Minnesota, Minnesota was projected to be the second highest state with catastrophic losses in 2013. The severe storm that affected Hennepin County on August 6, 2013, generated $800 million in claims across Minnesota.

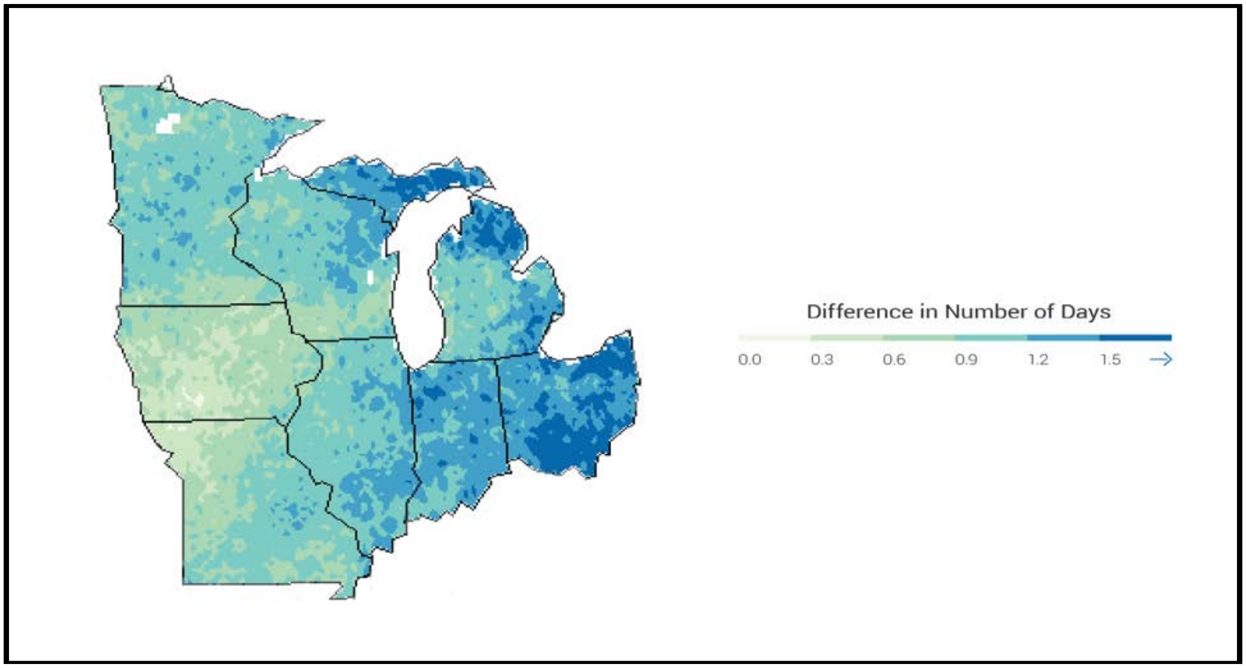
4.3.1.8. Future trends/likelihood of occurrence

Projections of future climates indicate that the area is likely to continue to see a rapid erosion of winter extreme cold temperatures, and it is expected that Hennepin County will fail to reach previously common benchmarks by increasingly large margins.

Extreme rainfall is projected to increase, but it should not be expected to do so on a year-after-year basis.

Instead, climate change is increasing the long-term frequency and magnitude of these events, meaning that storms of a certain size may come every 10-20 years instead of every 50 years. By mid-century, the area should receive an additional 3-8 days per decade with rainfall in the top 2% of the historical distribution (**GRAPHIC 4.3.1K**). Thus, the expectation is that unprecedented rainfall events will occur at some point this century, but their likelihood in the next decade will be limited by their overall statistical rareness.

GRAPHIC 4.3.1K Average difference in number of days per year by mid-century (2040-2070) with rainfall in upper 2% of distribution.

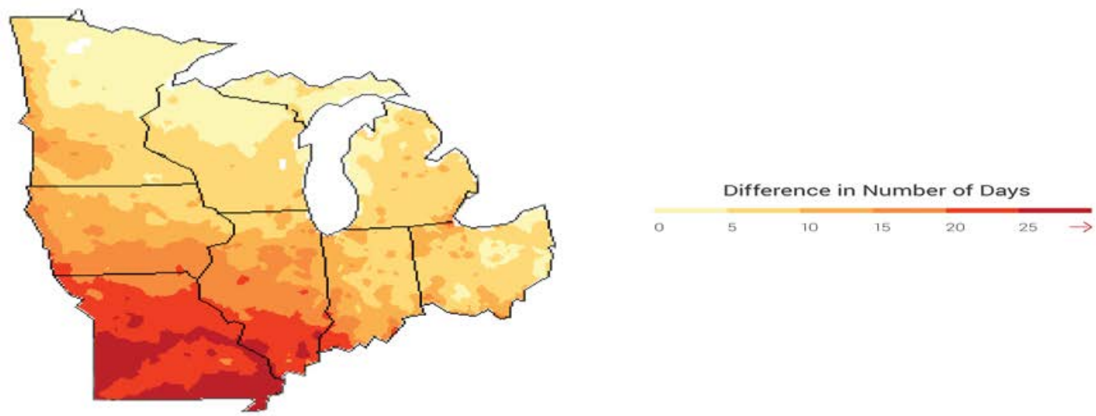


Snowfall and snowfall extremes may continue to increase over the next decade or so, in response to increased water vapor, but at some point, the continued warming of winter will limit the number of snowfall opportunities.

Severe convective storms and tornadoes are unlikely to remain at the current low incidence rates, and a "rebound" appears likely within the next decade, based on historical frequency alone. The association between this rebound and climate change will remain unclear, however. There has been some research into modeled projections of severe weather trends, but the conclusions range from decreases frequency and severity of events, to the exact opposite, including the possibility of large "super events," when a sufficiently high-shear environment overlays deep surface instability.

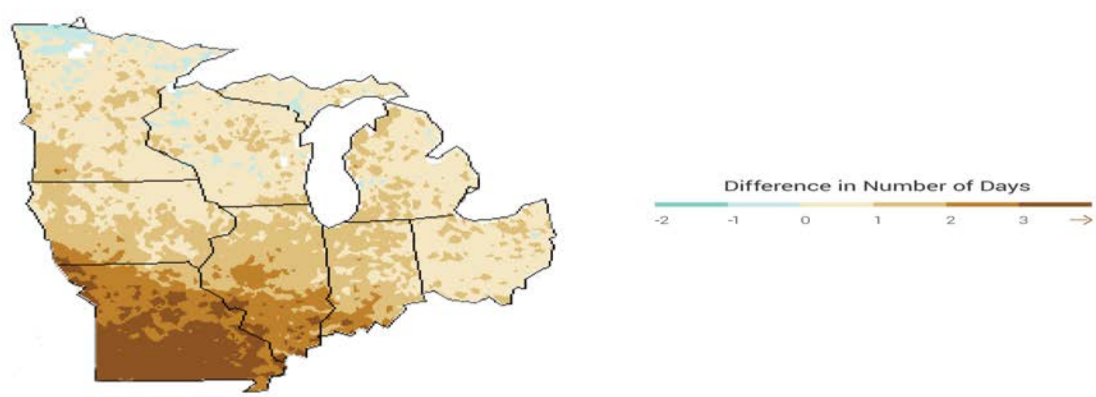
Heat waves are projected to increase significantly in Minnesota during the 21st century. Given the lack of any recent or ongoing trends, it is difficult to determine whether these should be expected within the next decade. However, projections indicate that by mid-century, the Twin Cities should expect 5-10 additional days per year above 95° F, which would in many cases more than double current frequencies **(GRAPHIC 4.3.1L)**

GRAPHIC 4.3.1L Difference in number of days per year by mid-century (2040-2070) maximum temperatures above 95° F.



It is less clear whether droughts will increase in frequency or severity as the climate changes. Though most models indicate a trend towards wetter conditions, many have indicated that the number of consecutive dry days will increase, posing some risk for increased drought potential (**GRAPHIC 4.3.1M**). If the expectation of increased heat waves is realized, droughts should have some increased frequency too.

GRAPHIC 4.3.1M Difference in number of *consecutive* days per year by mid-century (2040-2070) with less than 0.01 inches of precipitation. An increase in this variable is associated with an increase in the chance of drought in the future.



The strength of the expected impact of climate change on common Minnesota weather hazards between the years 2016 and 2025 is shown in **GRAPHIC 4.3.1N**. It should be noted that 10 years is a short period relative to climate change, and that normal inter-annual variability is likely to dominate the record. The continued warming of winter extremes is the most likely impact in Hennepin County. Unprecedented extreme rainfall events may occur, but their likelihood is limited by the short period and relatively small spatial domain of the county. As noted earlier, a return to an active severe weather pattern is likely. Despite lower overall confidence for heat waves and drought, a 10-year period exceeds the normal recurrence intervals of both types of events, so each should be expected. **GRAPHIC 4.3.1O** shows the same, except for the period beyond year 2026. The deeper time domain allows high confidence in at least one unprecedented extreme rainfall event, with at least slight increases in confidence in heat waves, drought and severe weather as well. The confidence in heavy snowfall is less than over the next decade, as winter warming reduces the hours of potential snowfall.

GRAPHIC 4.3.1N Confidence that various common Minnesota weather hazards will be impacted by climate change between 2016 and 2025.

Strength of *expected* impact from climate change

Highest	High	Moderately High	Moderately Low	Low	Lowest

Hazard	Expectations through 2025
Extreme cold	Continued decline in severity, frequency
Extreme rainfall	Unprecedented events possible
Heavy snowfall	Major events still likely as increased water vapor offsets increased temps
Severe thunderstorms & tornadoes	Return to active conditions likely but unpredictable
Heat waves	Expect at least one significant episode, even if within historical bounds
Drought	

GRAPHIC 4.3.1O Confidence that various common Minnesota weather hazards will be impacted by climate change beyond 2026.

Strength of *expected* impact from climate change

Highest	High	Moderately High	Moderately Low	Low	Lowest

Hazard	Expectations 2026 and beyond
Extreme cold	Cold benchmarks increasingly rare; former thresholds no longer reached
Extreme rainfall	Unprecedented events expected with increased frequency
Heavy snowfall	Large events less frequent, even if magnitude increases
Severe thunderstorms & tornadoes	More "super events" possible, even if frequency decreases
Heat waves	Increases in severity, coverage, and duration expected
Drought	Increases in severity, coverage, and duration expected

4.3.1.9. Indications and Forecasting

Chemists, biologist, physicists, oceanographers, geologists, and climatologist are all looking for indications of how the climate has been changing since beginning of time. Earth-orbiting satellites and other technological advances have enabled scientists to see the big picture, collecting many different types of information about our planet and its climate on a global scale. This body of data, collected over many years, reveals the signals of a changing climate. Some of the techniques used for looking at the climate of the past are:

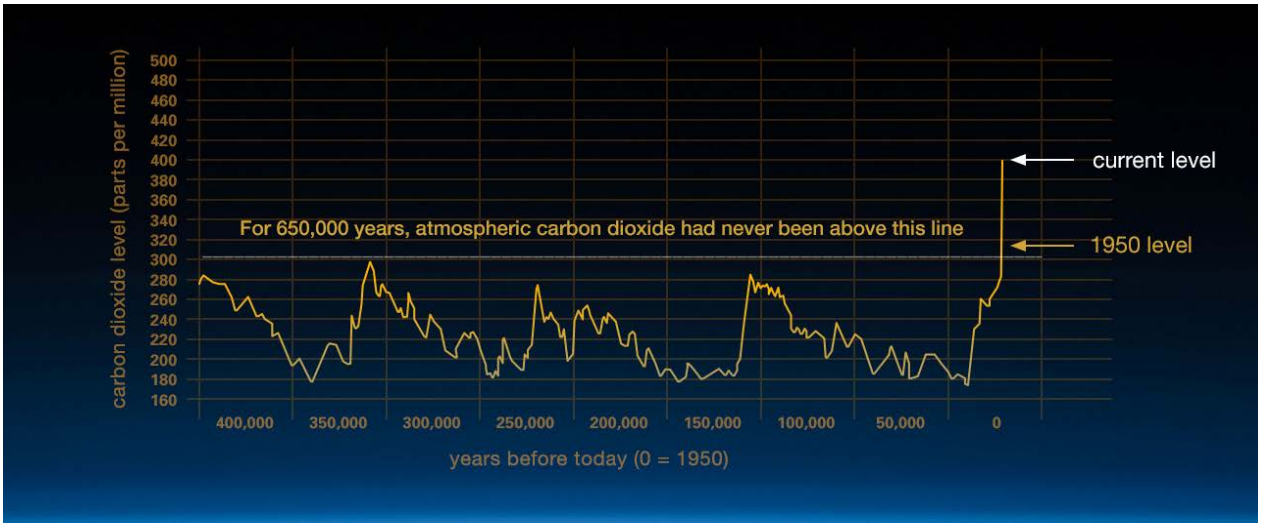
- Reading tree rings
- Air bubbles in Antarctic ice
- Measuring acidity temperature and salinity of our oceans at different depths.

By looking at characteristics of all aspects of the earth, scientists gain insight on past temperature, rainfall, carbon, and other parameters to look at how things might change in the future.

4.3.1.10. Detection & Warning

Scientists have been working to grab historic atmospheric carbon dioxide from ice cores, tree rings etc... In a report from NASA on Global Climate Change, states that the current level of atmospheric carbon dioxide has never been as high as it is right now in the past 650,000 years. **GRAPHIC 4.3.1P** shows this indication.

GRAPHIC 4.3.1P



While there are no warnings for climate change like tornado warnings, or flash flood warnings, we can look at the future trends section and notice we have a changing climate and take those forecasts and predictions as warnings for possible hazards and disasters to come in the future as a result of the changing climate.

4.3.1.11. Critical values and thresholds

Climate change is an ongoing phenomenon that manifests itself through the persistent change in the statistical behavior of climatic variables. Although no critical values and thresholds exist in Minnesota, the following indicators represent rare and/or uncharted territory in Hennepin County, and would indicate climate change mileposts:

- February ice-out, Lake Minnetonka; earliest on record is March 11, 1878
- Lack of zero or colder temperature at MSP; has not happened yet, and fewest such readings was two in 2001-02
- Winter temperature above 27° F --has only happened once, during “year without a winter” of 1877-78
- Low temperatures failing to reach -15° F
- No subzero high temperature
- Summer time minimum temperatures in excess of 80 degrees
- Tornadoes during March, October and/or November

4.3.1.12. Prevention

There is no way to prevent climate change from happening. However, in the mitigation section you will find strategies to reduce the effects as well as adaptation examples for the changing climate.

4.3.1.13. Mitigation

The overall risks of future climate change impacts can be reduced by limiting the rate and magnitude of climate change by efforts to reduce or prevent emission of greenhouse gases. Adaptation and mitigation are completer strategies for reducing and managing risks of climate change. Mitigation can mean using new technologies and renewable energies, making older equipment more energy efficient, or changing management practices or consumer behavior. It can be as complex as a plan for a new city, or as a simple as improvements to a cook stove design. Efforts underway around the world range from high-tech subway systems to bicycling paths and walkways. Protecting natural carbon sinks like forests and oceans, or creating new sinks through green agriculture are also elements of mitigation. Adaptation examples are shown in **Table 4.3.1G**.

Table 4.3.1G.

Category	Examples
Human Develop.	Improved access to education, nutrition, health facilities, energy, safe housing & settlement structures, & social support structures; Reduced gender inequality & marginalization in other forms.
Poverty Alleviation	Improved access to & control of local resources; Land tenure; Disaster risk reduction; Social safety nets & social protection; Insurance schemes.
Livelihood Security	Income, asset & livelihood diversification; Improved infrastructure; Access to technology & decision- making fora; Increased decision-making power; Changed cropping, livestock & aquaculture practices; Reliance on social networks.
Disaster Risk Management	Early warning systems; Hazard & vulnerability mapping; Diversifying water resources; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements.
Ecosystem Management	Maintaining wetlands & urban green spaces; Coastal afforestation; Watershed & reservoir management; Reduction of other stressors on ecosystems & of habitat fragmentation; Maintenance of genetic diversity; Manipulation of disturbance regimes; Community-based natural resource management.
Spatial or land-use planning	Provisioning of adequate housing, infrastructure & services; Managing development in flood prone & other high risk areas; Urban planning & upgrading programs; Land zoning laws; Easements; Protected areas.
Structural/ Physical	***Engineered & built-environment options***: Sea walls & coastal protection structures; Flood levees; Water storage; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements; Floating houses; Power plant & electricity grid adjustments.
	Technological options: New crop & animal varieties; Indigenous, traditional & local knowledge, technologies & methods; Efficient irrigation; Water-saving technologies; Desalinization; Conservation agriculture; Food storage & preservation facilities; Hazard & vulnerability mapping & monitoring; Early warning systems; Building insulation; Mechanical & passive cooling; Technology development, transfer & diffusion.
	Ecosystem-based options: Ecological restoration; Soil conservation; Afforestation & reforestation; Mangrove conservation & replanting; Green infrastructure (e.g., shade trees, green roofs); Controlling overfishing; Fisheries co-management; Assisted species migration & dispersal; Ecological corridors; Seed banks, gene banks & other *ex situ* conservation; Community-based natural resource management.

	Services: Social safety nets & social protection; Food banks & distribution of food surplus; Municipal services including water & sanitation; Vaccination programs; Essential public health services; Enhanced emergency medical services.
Institutional	***Economic options***: Financial incentives; Insurance; Catastrophe bonds; Payments for ecosystem services; Pricing water to encourage universal provision and careful use; Microfinance; Disaster contingency funds; Cash transfers; Public-private partnerships.
	Laws & regulations: Land zoning laws; Building standards & practices; Easements; Water regulations & agreements; Laws to support disaster risk reduction; Laws to encourage insurance purchasing; Defined property rights & land tenure security; Protected areas; Fishing quotas; Patent pools & technology transfer.
	National & government policies & programs: National & regional adaptation plans including mainstreaming; Sub-national & local adaptation plans; Economic diversification; Urban upgrading programs; Municipal water management programs; Disaster planning & preparedness; Integrated water resource management; Integrated coastal zone management; Ecosystem-based management; Community-based adaptation.
Social	***Educational options***: Awareness raising & integrating into education; Gender equity in education; Extension services; Sharing indigenous, traditional & local knowledge; Participatory action research & social learning; Knowledge-sharing & learning platforms.
	Informational options: Hazard & vulnerability mapping; Early warning & response systems; Systematic monitoring & remote sensing; Climate services; Use of indigenous climate observations; Participatory scenario development; Integrated assessments.
	Behavioral options: Household preparation & evacuation planning; Migration; Soil & water conservation; Storm drain clearance; Livelihood diversification; Changed cropping, livestock & aquaculture practices; Reliance on social networks.
Spheres of change	***Practical***: Social & technical innovations, behavioral shifts, or institutional & managerial changes that produce substantial shifts in outcomes.
	Political: Political, social, cultural & ecological decisions & actions consistent with reducing vulnerability & risk & supporting adaptation, mitigation & sustainable development.
	Personal: Individual & collective assumptions, beliefs, values & worldviews influencing climate-change responses.

4.3.1.14. Response

- *Hennepin County Emergency Operations Plan*

4.3.1.15. Recovery

Because it is very difficult to link a specific events to climate change, it is difficult to discuss recovery as it pertains to climate change versus each individual event as in other hazards. Please refer to the other hazard sections to review recovery from the specific hazard.

4.3.1.16. References

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4.3.2.	Hazard Assessment: TORNADO

4.3.2.1. Definition

A tornado is defined as a violently rotating column of air that reaches from a wall cloud or updraft base of a severe thunderstorm to the ground. The majority of tornadoes occur in severe thunderstorms, but not all severe thunderstorms will contain tornadoes. Tornado development depends on either condensed moisture from above and/or dust or debris from the surface to become visible. The wind speeds, width, duration and length of travel of tornadoes vary widely. The degree of destruction depends on both the characteristics of the tornado and of what has been hit. Tornadoes may form alone or in some instances they may have satellites or twins that are in close proximity. Some regions may experience several tornadoes that form during a few hours in a phenomenon called an outbreak. Outbreaks that repeat over several days are called an outbreak sequence.

4.3.2.2. Range of Magnitude

Tornadoes can appear in a variety of shapes and sizes ranging from large wedge shapes with a diameter greater than a mile down to thin rope like circulations. The strongest tornadoes can have wind speeds in excess of 200 mph. Tornado wind speeds are estimated after the fact based on the damage they produce. Tornadoes are characterized on a scale of 0 (weakest) to 5 (strongest) according to the Fujita (F) or Enhanced Fujita (EF) Scale. The original Fujita Scale was devised in 1971 by Dr. Ted Fujita of the University of Chicago. The scale gives meteorologist the ability to rate from F0 to F5 based upon the type and severity of damage that the tornado produced. At that time, there were very few actual measurements of tornado wind speeds that he could relate to the damage, but Dr. Fujita used them together with a lot of insight to devise approximate wind speed ranges for each damage category.

In subsequent years, structural engineers have examined damage from many tornadoes. They use knowledge of the wind forces needed to damage or destroy various buildings and their component parts to estimate the wind speeds that caused the observed damage. What they found was that the original Fujita Scale wind speeds were too high for categories F3 and higher, which may have led to inconsistent ratings, including possible overestimates of associated wind speeds.

With these inconsistent ratings in mind, a panel of meteorologists and engineers convened by the Wind Science and Engineering Research Center at Texas University devised the new Enhanced Fujita Scale, which became active as of February 1, 2007. The EF Scale incorporates more damage indicators and degrees of damage than the original “F” Scale, allowing more detailed analysis and better correlation between damage and wind speed. You can see both scale charts below **TABLE 4.3.2A**.

TABLE 4.3.2A Fujita Scale

Fujita Scale		Enhanced Fujita Scale* * In use since 2007	
F–0	40–72 mph winds	EF–0	65–85 mph winds
F–1	73–112 mph	EF–1	86–110 mph
F–2	113–157 mph	EF–2	111–135 mph
F–3	158–206 mph	EF–3	136–165 mph
F–4	207–260 mph	EF–4	166–200 mph
F–5	261–318 mph	EF–5	>200 mph

The follow are records from around the County as well as Hennepin County.

Maximum wind speed

- United States
    - 318 MPH (Moore, OK, May 3, 1999)
- Hennepin County
    - 166-200 (estimated)

Maximum width

- United States
    - 2.6 miles (El Reno, OK Tornado, May 31, 2013)
- Hennepin County
    - 880 Yards (St. Louis Park, May 22, 2011)

Longest track

- United States
    - 235 miles (Tri-State Tornado, March 18, 1925)
- Hennepin County
    - Hennepin: 70.9 Miles (June 23, 1952)

Fastest forward motion:

- United States
    - 73MPH (Tri-State Tornado, March 18, 1925)
- Hennepin County
    - 30 MPH (Champlin-Anoka Tornado, June 18th 1939)[4]

Largest outbreak

- United States
    - 211 tornadoes in 24 hours (SE US outbreak, April 27, 2011)
- Hennepin County

  - 3 tornadoes in 3 hours (May 6, 1965)

Longest duration

- United States
  - 3.5 hours (Tri-State Tornado, March 18, 2915)

Greatest pressure drop

- United States
  - 100 milibars (Manchester, SD, June 24, 2003). *An unofficial drop of 194 millibars was noted from the Tulia, TX tornado on April 21, 2007.

Costliest tornado

- United States
  - $2.9 billion (Joplin, MO, May 22, 2011)

Deadliest tornado

- United States
  - 695 killed (Tri-State Tornado, March 18, 1925)

Deadliest modern day tornado

- United States
  - 158 killed (Joplin, MO, May 22, 2011)

Deadliest tornado outbreak

- United States
  - 747 killed (Tri-State Outbreak, March 18, 1925)

Deadliest modern day outbreak

- United States
  - 324 killed (SE US Outbreak, April 25-28, 2011)

4.3.2.3. Spectrum of Consequences

The consequences from tornadoes can range from minor damage and injuries to complete destruction and death. Please see the chart below (**TABLE 4.3.2B**) that correlates the EF rating scale with the expected damage seen.

TABLE 4.3.2B EF Rating Scale

EF Rating	Wind Speeds	Expected Damage		
EF-0	65-85 mph	'Minor' damage: shingles blown off or parts of a roof peeled off, damage to gutters/siding, branches broken off trees, shallow rooted trees toppled.		
EF-1	86-110 mph	'Moderate' damage: more significant roof damage, windows broken, exterior doors damaged or lost, mobile homes overturned or badly damaged.		
EF-2	111-135 mph	'Considerable' damage: roofs torn off well constructed homes, homes shifted off their foundation, mobile homes completely destroyed, large trees snapped or uprooted, cars can be tossed.		
EF-3	136-165 mph	'Severe' damage: entire stories of well constructed homes destroyed, significant damage done to large buildings, homes with weak foundations can be blown away, trees begin to lose their bark.		
EF-4	166-200 mph	'Extreme' damage: Well constructed homes are leveled, cars are thrown significant distances, top story exterior walls of masonry buildings would likely collapse.		
EF-5	> 200 mph	'Massive/incredible' damage: Well constructed homes are swept away, steel-reinforced concrete structures are critically damaged, high-rise buildings sustain severe structural damage, trees are usually completely debarked, stripped of branches and snapped.		

4.3.2.4. Potential for Cascading Effects

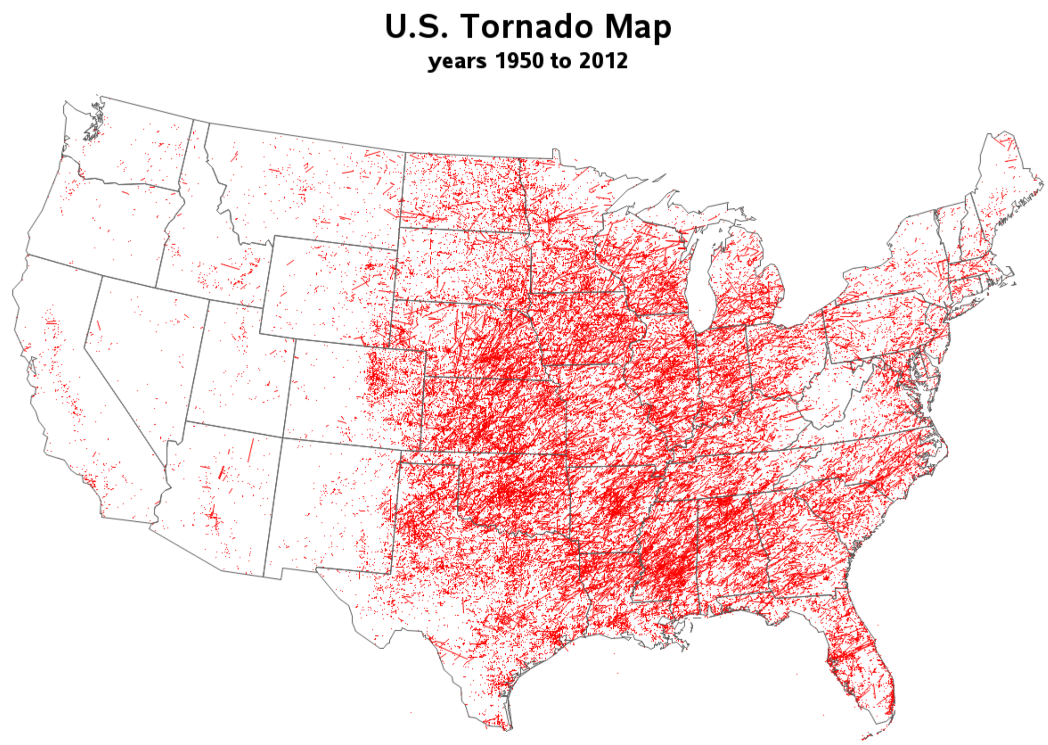
Beyond the destruction and lives that tornadoes leave behind, there are many cascading events or hazards that can follow. First, as mentioned, tornadoes are more prominent in the summer months. If a tornado takes out a power source and there is expected high heat to follow, you have now increased the number of people vulnerable to extreme heat event consequences with lack of power or a way to keep cool. If a tornado disrupts farming is anyway, this can lead to food shortages and/or disrupt the food chain. As debris is deposited anywhere and everywhere from a tornado, this can lead to water contamination, and a fire hazard with lumber from houses, buildings and trees amongst damaged power lines and gas leaks.
Another consequence is the economy impact. Indirect losses that occur from the destruction of a tornado are hard to estimate directly after an event. Losses could include lost production, sales, incomes and labor time, increased commute times and transportation costs from goods having to be rerouted, decreased tourist activity, and utility disruptions. Some people might lose their jobs all together. The decreased

economic activity also results in lost taxable receipts and uses up federal disaster relief funds in order to help the clean-up, repair, and replacing of loss assets. Loss of production an also result in surging prices due to shortages. A well-known example of this occurred when refineries were affected by a tornado in the southern United States in 2011, which caused gas prices to rise.

4.3.2.5. Geographic Scope of Hazard

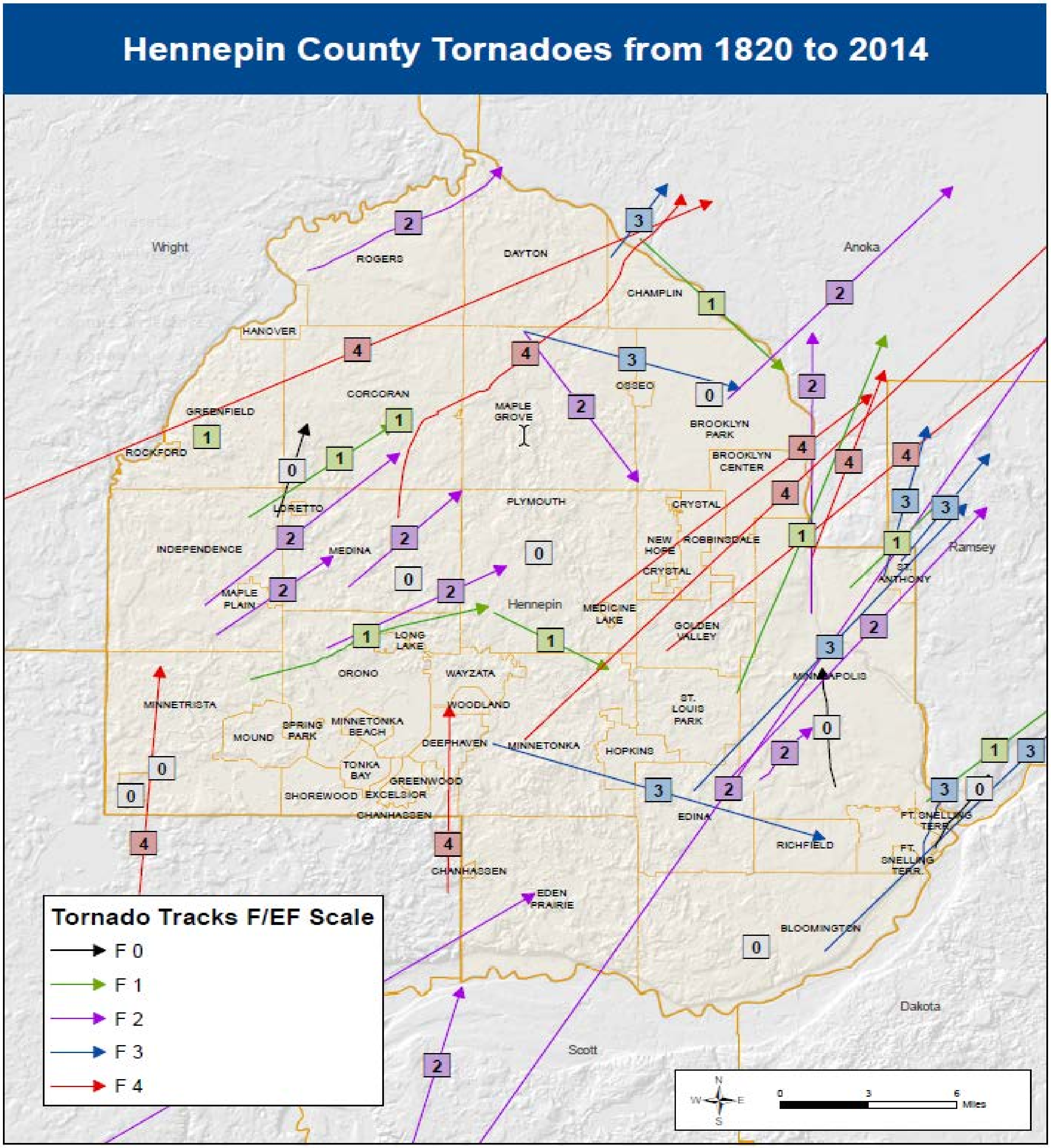
The United States has the highest incidence of tornadoes worldwide, with more than 1,000 occurring every year. This is due to the unique geography that brings together polar air from Canada, tropical air from the Gulf of Mexico, and dry air from the Southwest to clash in the middle of the country, producing thunderstorms and the tornadoes. The illustration below (**GRAPHIC 4.3.2A**) provides all tornadoes that have occurred from 1950-2012 as plotted by the Storm Prediction Center.

GRAPHIC 4.3.2A National Tornado Occurrence Map 1950-2012



The illustration below (**GRAPHIC 4.3.2B**) provides all tornadoes that have occurred from 1820-2014 as listed by Hennepin County Archives.

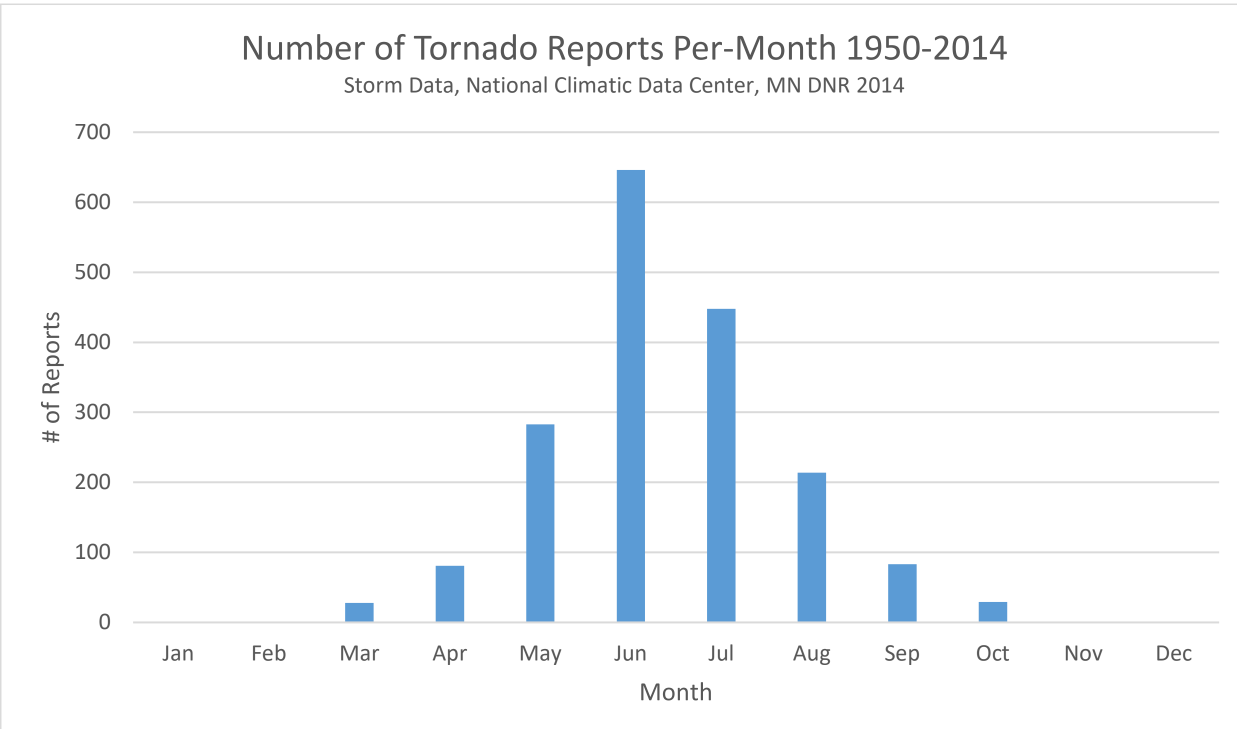
GRAPHIC 4.3.2B Hennepin County Tornado Occurrence map 1820-2014



4.3.2.6. Chronological Patterns

Tornadoes can occur during any time of day and any time of year. However, the majority of tornadoes have occurred in the afternoon hours and during the months of May through August. The graphic below (**GRAPHIC 4.3.2C**) shows the tornado reports nationally from 1950-2014. You can see in the chart that tornadoes occur (and are reported) more typically starting in April through September with the greatest months being June and July. These two months are typically identified as Minnesota's tornado season.

GRAPHIC 4.3.2C

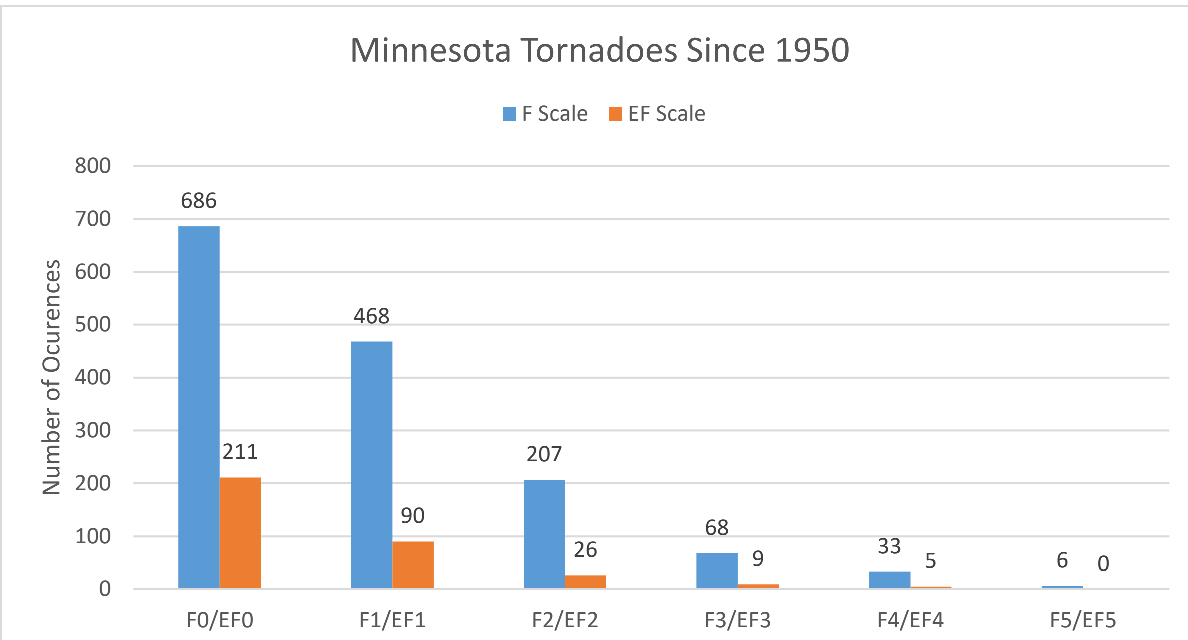


4.3.2.7. Historical Data/previous occurrence

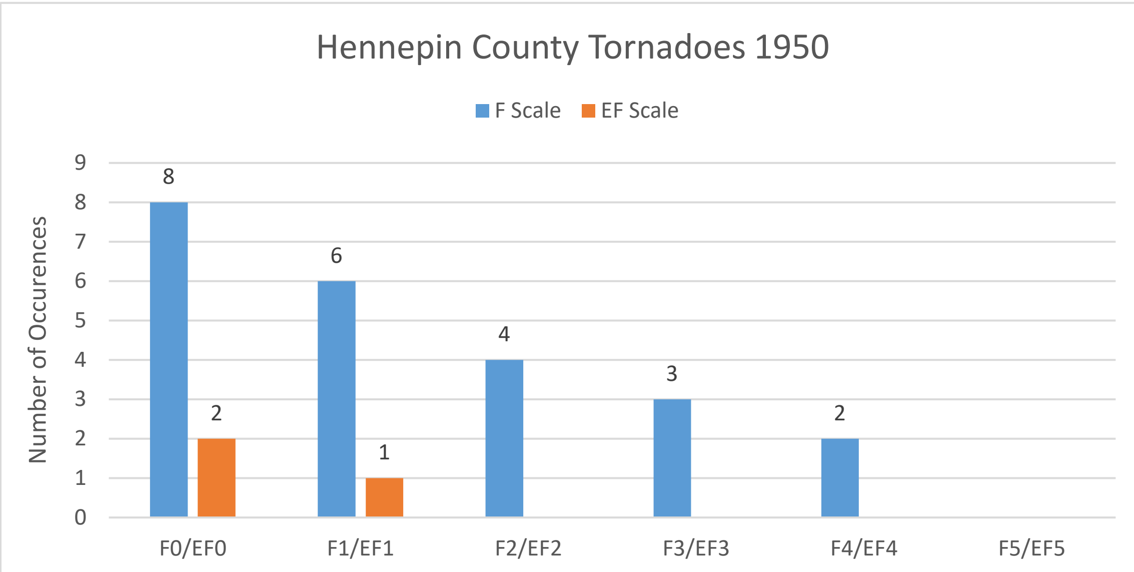
Native peoples in tornado-prone areas such as Hennepin County experienced tornadoes and developed oral traditions to explain them. The first written record of an American tornado is from July 8, 1680 in Cambridge, MA. The first officially-recorded tornado in Minnesota was sighted near Fort Snelling in Hennepin County on April 19, 1820. Because tornadoes are more numerous in the United States than any other nation, tornadoes have been studied here more than anywhere else. In 1882, the U.S. Army Signal Corps assigned Sgt. John Finley to investigate weather conditions that form tornadoes. Technology limits made the early understanding of tornado anatomy difficult. The adoption of radar revolutionized the study and forecasting of tornadoes. The first US Weather Bureau radar in Minnesota was installed at the Minneapolis-Saint Paul International Airport in the early 1960s. Air Force meteorologists issued the first tornado forecast in March 1948. The US Weather Bureau followed suit by 1952. Important advancements in understanding tornadoes were made by Theodore Fujita who studied tornado formation and damage across the Midwest in the 1960s and 70s. Modern era radar was installed at the Twin Cities office of the National Weather Service in 1996.

In Minnesota and Hennepin County, the record of tornado sightings encompasses nearly 200 years from records kept at Fort Snelling. The local newspaper record, which often contain notices of weather events, goes back over 160 years. In general, early reports are incomplete and may contain some factual errors. As settlement and population density increased, human interactions with tornadoes also increased. Reports became more numerous. **GRAPHIC 4.3.2D** and **GRAPHIC 4.3.2E** depict standardized and reliable tornado data in Minnesota and in Hennepin County extending back to 1950. Advanced technology has made detection easier and resulted in more reports of weak tornadoes.

GRAPHIC 4.3.2D



GRAPHIC 4.3.2E



4.3.2.8. Future Trends

When looking at trends of tornado occurrences, one must keep in mind how reporting has changed over the last decade as well as population increase. With more people covering a larger geographical area than 100 years ago, there is bound to be more reports of tornadoes occurring because people are actually there to see them. Actually, there seems to be no trend since 1954 of the occurrence of F1 and stronger tornadoes and increase in tornado reports results from an increase in the weakest tornadoes, F0. If just looking at stronger events being reported, you can run into the problem of changes in tornado damage assessment procedures in trend identification.

Taking out changes in population and reporting measures, there is less trend actually in the amount of tornadoes per year, as in there doesn't seem to be a growing amount of tornadoes each year, or less for that matter. Research does show there seem to be more extreme swings in tornadoes per year. While years have always varied in terms of number of tornadoes, they generally fell between a certain ranges. In the past decade however, researchers have started seeing toad counts that have deviated well outside of that range. Another trend researchers are seeing is the number of tornado days seems to be decreasing, while the number of tornadoes per day has been increasing.

Researchers have also been looking into trends on when the 'tornado season' starts. The average start days of tornadoes is March 22nd, and that has not changed (tornado season start is defined as first 50 tornadoes of F1/EF1 strength have been reported). However, there have been more late and early starts to the season in recent years. Seven of the 10 earliest tornado starts have occurred since 1996, and four of the latest starts occurred between 1999 and 2013 of 60 years of records.

4.3.2.9. Indications and Forecasting

National responsibility for developing tornado indications and forecasts rests with the National Weather Service's Storm Prediction Center (SPC) in Norman, Oklahoma. The SPC issues daily Convective Weather Outlooks. These outlooks give general categories that explain the chances/risk of tornadoes each day. As conditions look to develop more favorable for tornadic storms to occur, SPC will issue Mesoscale Discussions (MDs). MDs contain a graphical depiction of the mesoscale convective developments, an areas affected line, concerning line, valid time, a summary paragraph summary, and a paragraph for a technical discussion. There are five categories of concern issued with the MD:

- Severe Potential…Watch Unlikely (5 or 20%)
- Severe Potential…Watch Possible (40 or 60%)
- Severe Potential…Watch likely (80 or 95%)
- Severe Potential…Tornado Watch likely (80 or 95%)
- Severe Potential…Severe Thunderstorm Watch Likely (80 or 95%)
- Severe Potential…Watch Needed Soon (95%)

After an MD is issued, SPC will monitor conditions and if tornadic potential still is likely, they will issue a tornado watch. A tornado watch is issued when atmospheric conditions are favorable for the development of severe thunderstorms capable of producing tornadoes. On average, Hennepin County is included in 5 tornado watches each year. In addition to the SPC's information about potential for tornadoes, the National Weather Service Forecast Office will issue Hazardous Weather Outlook (HWO) based on their thoughts for the potential of tornadoes occurring. In this discussion, they will highlight the best time, and generally geographic location for storms to occur.

4.3.2.10. Detection and Warning

National responsibility for detection and warning of tornadoes falls on the local National Weather Service's Weather Forecast Offices (WFO). The local WFO for Hennepin County is located in Chanhassen, MN. One of the systems the WFO uses to detect tornadoes is RADAR. There are actually two RADAR sites that the Chanhassen WFO uses, the NEXRAD WSR-88D and the Terminal RADAR. The NEXRAD WSR-88D is located at the Chanhassen WFO office, and the Terminal RADAR is located in Woodbury and is used daily for incoming aircraft. There are many different products that the NWS can use from these RADARS that help them detect whether or not a storm has a tornadic signature to it.

Another avenue that the WFO uses are spotter reports, or reports from emergency managers. In the metro region, there is an organized amateur radio group called Metro SKYWARN that teach SKYWARN spotter classes to amateur radio operators so they can make reports directly to the local WFO.

If the WFO sees evidence that there is a tornado either on the ground, or the potential, they will issue a tornado warning. A tornado warning means a severe thunderstorm has developed and has either produced a tornado or radar has indicated intense low-level rotation in the presence of atmospheric conditions conductive to tornado development. On average, Hennepin County is in a tornado warning between 30 and 45 minutes a year. Once a tornado warning has been issued, there are a variety of notification systems that notified automatically in which they then send off the notification of tornado warning as well: Wireless Emergency Alerts (WEA), Outdoor Warning Sirens, Digital Message Signs, IPAWS, and NOAA Weather Radios. In addition to the automatic notification, television and radio station may also begin to broadcast the warning information.

4.3.2.11. Critical Values and Thresholds

According to NOAA, there is no single critical threshold values to confirm or predict the occurrence of tornadoes of a particular intensity without looking at damage. The critical values of the F & EF tornadoes scales can be seen above in the *Range of Magnitude* section.

4.3.2.12. Prevention

There is nothing you can do to prevent a tornado from occurring. However, you can prevent some of the consequences from occurring by being prepared. Always be aware of the weather forecast and if there is a possibility of severe weather. Having a local weather source you trust and receiving timely information can prevent one from being caught off guard.

4.3.2.13. Mitigation

While there is no way to prevent a tornado from occurring, you can prevent some of the consequences from occurring by being weather aware for life safety, build safe rooms for sheltering or retrofit walls to safe room standard. Here are some of the ideas from the FEMA Mitigations Handbook

Education and Awareness Programs:
- Conduct outreach activities to increase awareness of tornado risk and impacts.
- Educate citizen through media outlets
- Conducting tornado drills in schools and public buildings
- Teaching schoolchildren about the dangers of tornadoes and how to take safety precautions.
- Distributing tornado shelter location information
- Supporting severe weather awareness week
- Promoting use of National Oceanic and Atmospheric Administration (NOAA) Weather Radios.

Construction of Safe Rooms:
- Requiring construction of safe rooms in new schools, daycares, and nursing homes.
- Encouraging the construction and use of safe rooms in homes and shelter areas of manufactured home parks, fairgrounds, shopping malls, or other vulnerable public structures.
- Encouraging builders and homeowners to locate tornado safe rooms inside or directly adjacent to houses to prevent injuries due to flying debris or hail.
- Developing a local grant program to assist homeowners who wish to construct a new safe room.

Require Wind-Resistant Building or Retrofitting Techniques:

- Structural bracing
- Straps and Clips Anchor Bolts
- Laminated or impact-resistant glass
- Reinforcement pedestrian and garage door

4.3.2.14. Response

Hennepin County Emergency Management Capabilities

- Situation monitoring Station (SMS)
- HCEM Immediate Impact Reconnaissance Teams
- Mutual Aid

4.3.2.15. Recovery

There are two types of recovery, short term and long term. Initial short-term recovery can be getting the power back on or cleaning up debris. There are many things to consider when talking about long-term recovery. Depending on the extend of the tornado and location, large wooded areas can pose a fire threat, so damaged trees and branches need to be managed. Another important consideration is business recovery. It took Joplin 3 years to be able to re-build their hospital and high school. Other businesses have been shown the struggle for one or more years after a disaster. Another consideration of recovery is the mental recovery of not only victims, but of the rescue workers that responded and helped during the initial short-term recovery process.

4.3.2.16. References

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4.3.3.	Hazard Assessment: WIND, EXTREME STRAIGHT-LINE

4.3.3.1. Definition

A *Derecho* is an extreme, widespread, and long-lived wind storm. They are associated with bands of rapidly moving showers or thunderstorms variously known as bow echoes, squall lines, or quasi-linear convective systems.

Although a derecho can produce destruction similar to that of a tornado, the damage typically occurs in one direction along a relatively straight path. As a result, the term "straight-line wind damage" sometimes is used to describe derecho damage. By definition, if the swath of wind damage extends for more than 240 miles, includes wind gusts of at least 58 mph along most of its length, and several, well-separated 75 mph or greater gusts, then the event may be classified as a derecho.

4.3.3.2. Range of magnitude

Maximum wind speeds:
- Hennepin:
  - 100 mph, Wold-Chamberlain Field (MSP), July 20, 1951
  - 86 mph at Flying Cloud Airport, on 15 July 1980
- Other Twin Cities Metro:
  - 110 mph sustained, gust 180 mph, St. Paul, Aug 20, 1904
- Minnesota:
  - 121 mph, Donaldson, MN, September 1, 2011
  - 117 mph, Alexandria, July 19, 1983
- Region: 128 MPH (Northeast of Madison, WI May 31, 1998)

Maximum width: 100 miles (Kansas – The "Super Derecho of May 8, 2009)
Longest track: 1300 miles (The Boundary Waters-Canadian Derecho July 4-5, 1999)
Longest duration: 22 hours (The Boundary Waters-Canadian Derecho July 4-5, 1999)
Costliest US Derecho: $1 Billion (1995) (The Ontario-Adirondacks Derecho of July 14-15, 1995)
Deadliest US Derecho: 73 killed (The "More Trees Down" Derecho July 4-5, 1980)

4.3.3.3. Spectrum of Consequences

Because derechos are most common in the warm season, those involved in outdoor activities are most at risk. Campers or hikers in forested areas are vulnerable to being injured or killed by falling trees. Boaters risk injury or drowning from storm winds and high waves that can overturn boats.

Occupants of cars and trucks also are vulnerable to being hit by falling trees and utility poles. Further, high profile vehicles such as semi-trailer trucks, buses, and sport utility vehicles may be blown over. At outside events such as fairs and festivals, people may be killed or injured by collapsing tents and flying debris. Even those indoors may be at risk for death or injury during derechos. Mobile homes, in particular, may be overturned or destroyed, while barns and similar buildings can collapse. People inside homes, businesses, and schools are sometimes victims of falling trees and branches that crash through walls and roofs; they also may be injured by flying glass from broken windows. Finally, structural damage to the building itself (for example, removal of a roof) could pose danger to those within.

Another reason that those outdoors are especially vulnerable to derechos is the rapid movement of the parent convective system. Typically, derecho-producing storm systems move at speeds of 50 mph or greater, and a few have been clocked at 70 mph. For someone caught outside, such rapid movement means that darkening skies and other visual cues that serve to alert one to the impending danger (e.g., gust front shelf clouds) appear on very short notice.

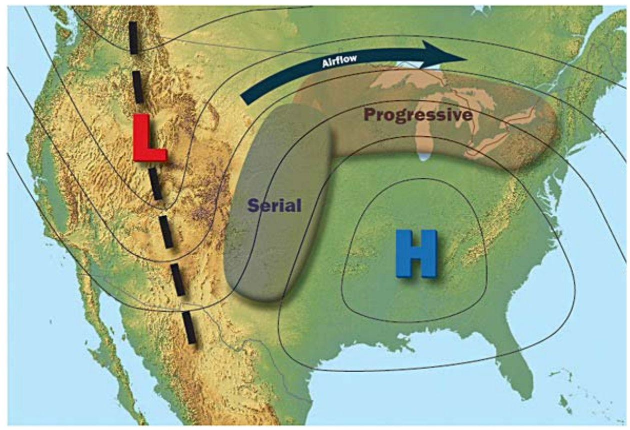
Whether in an urban or rural area, those out-of-doors are at greatest risk of being killed or injured in a derecho. But of particular significance in urban areas is the vulnerability of electrical lines to high winds and falling trees. In addition to posing a direct hazard to anyone caught below the falling lines, derecho damage to overhead electric lines sometimes results in massive, long-lasting power outages. Hundreds of thousands of people may be affected; in the worst events, power may not be restored for many days.

It is the complex and dense concentration of overhead distribution feeders in urban areas --- and their frequent proximity to large trees --- that make cities especially vulnerable to electrical outages following derechos. The density and mileage of overhead electric distribution lines in urban areas far exceeds that of any rural or exurban area. Pole lines often carry multiple circuits and voltages, as well as lines for street lighting and customer service connections that further add to the vulnerability. Because of this, and because urban electrical feeders typically serve smaller territories relative to their rural counterparts, significantly greater manpower is necessary to restore service after major storms. In addition, unlike the localized damage produced by a tornado, derecho damage may be widespread. As a result, repairs often require greater effort, with additional delays related to shortages in supplies.

4.3.3.4. Potential for cascading effects

- *Flash Flooding* - On occasion, on the rear flank of a convective system responsible for a progressive derecho, a nearly stationary band of thunderstorms may form. If such a band persists for an extended period flash flooding may follow. As individual storms grow and mature, they move parallel to the boundary, causing multiple episodes of heavy rain at locations along the line. Such convective evolution is known as echo training**.** Prolonged echo-training in a moisture-rich environment nearly always results in flash flooding. Smaller scale or more intermittent episodes of echo training frequently occur on the rear flanks of progressive derechos, and may cause localized flooding in the wake of a derecho's high winds.

- *Power Outages* - Some of the most intense summer derechos occur on the fringes of major heat waves. The primary link between heat waves and derechos is the presence of an elevated mixed layer, or EML. An EML is a layer of mid-tropospheric air that originates over the arid, elevated terrain. Because of their origin, EMLs exhibit sharp decreases in temperature with height. The large vertical temperature differentials (or "steep" lapse rates) in EMLs are analogous to those observed over black-topped roofs and parking lots on sunny days. Such thermal stratification encourages the formation of strong updrafts that can lead to the development of thunderstorms.



This map illustrates the large-scale meteorological environment favorable for progressive derechos on the northern fringe of a high pressure cell associated with a major heat wave over central and eastern United States.

Since derecho can occur during intense heat waves, one of the most dangerous cascading effects is the damage to electrical infrastructure post storm. Once the storms pass, heat waves usually persist and residents are left without the benefit of air-conditioning and are at times having to deal with triple digit heat. This sort of cascading effect occurred as recently as 29 June 2012, when a derecho of historic proportions struck the Ohio Valley and Mid-Atlantic states. The derecho traveled for 700 miles, impacting 10 states and Washington, D.C. An estimated 4 million customers lost power for up to a week. The region impacted by the derecho was also in the midst of a heat wave. Heat claimed 34 lives in areas without power following the derecho.

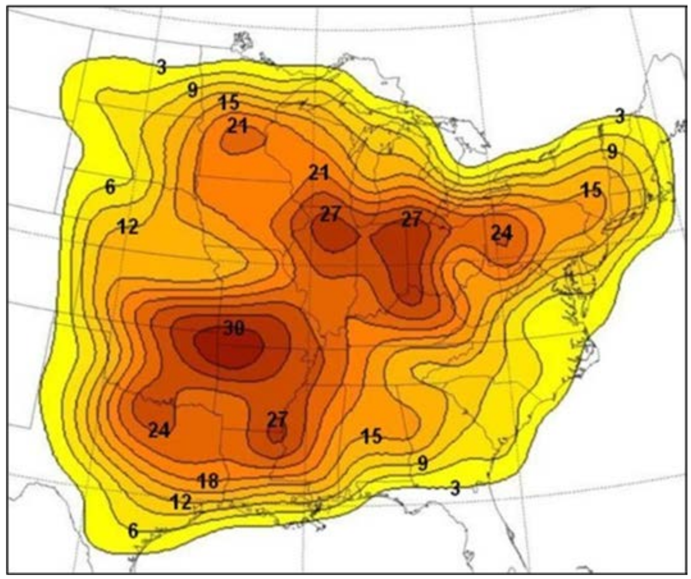
Wildland Fires – Derecho's can obliterate millions of trees across miles of forest due to the extreme winds associated with them. This increases fuel loads on forests and escalates the risk of wildland fire.

Tornadoes - Derechos and tornadoes can occur with the same convective system. This is particularly so with serial derechos associated with strong, migratory low pressure systems. The tornadoes may occur with isolated supercells ahead of the derecho producing squall line, or they may develop from storms within the squall line itself. Although not as common, tornadoes sometimes occur with progressive derechos. When they do, the tornadoes typically form within the bow echo storm system itself, and only rarely are associated with isolated supercells ahead of the-bow.

The occurrence of tornadoes with derecho-producing convective systems reflects the fact that both tornadoes and strong convective wind gusts share, to some extent, common origins in the background atmospheric environment. In short, the great degree of thermodynamic instability; i.e., buoyancy, that gives rise to strong updrafts and, ultimately, the thunderstorms that spawn tornadoes also promotes the formation of storm downdrafts. In addition, both tornado and derecho environments are characterized by the presence of substantial vertical wind shear; i.e., large changes in wind speed and/or direction with height. While derecho-producing convective systems tend to be **most** favored when the vertical wind profile is unidirectional, a unidirectional wind profile may still contain appreciable shear. At the same time, in even a modestly sheared environment, small-scale stretching and tilting motions often present along storm gust fronts in a squall line may yield low-level circulations that, on occasion, can "tighten up" into a tornado.

4.3.3.5. Geographic Scope of Hazard

Derechos most commonly occur along two axes. One track parallels the "Corn Belt" from the upper Mississippi Valley southeast into the Ohio Valley; the other extends from the southern Plains northeast into the mid-Mississippi Valley. During the cool season (September through April), derechos are relatively infrequent but are most likely to occur from east Texas into the southeastern states. Although derechos are rare west of the Great Plains, derechos occasionally do occur over interior portions of the western United States, especially during spring and early summer.



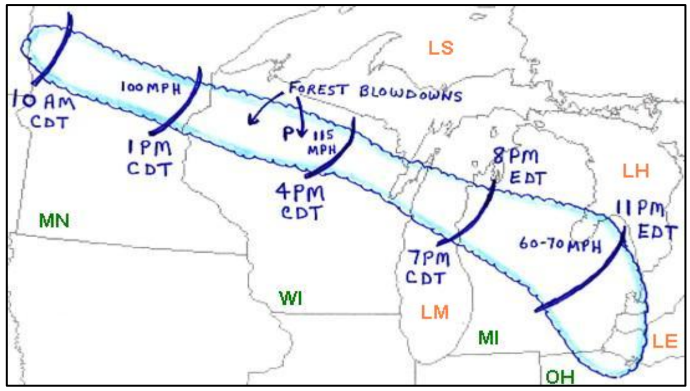
Approximate number of times "moderate and high intensity" (MH) derechos affected points in the United States during the years 1980 through 2001. Areas affected by 3 or more derecho events are shaded in yellow, orange, and red.

The highest annual frequencies of occurrence appear along the "Corn Belt," from Minnesota and Iowa into western Pennsylvania, and in the south central states, from eastern parts of the southern Plains into the lower Mississippi Valley. However, the frequencies vary by season. During the warm season (May through August), derecho events are most frequent in the western part of the Corn Belt. During the remainder of the year (September through April), the maximum frequencies shift south into the lower Mississippi Valley

4.3.3.6. Chronologic patterns (seasons, cycles, rhythm)

Derechos in the United States are most common in the late spring and summer (May through August), with more than 75% occurring between April and August. The seasonal variation of derechos corresponds rather closely with the incidence of thunderstorms.

4.3.3.7. Historical data/previous occurrence

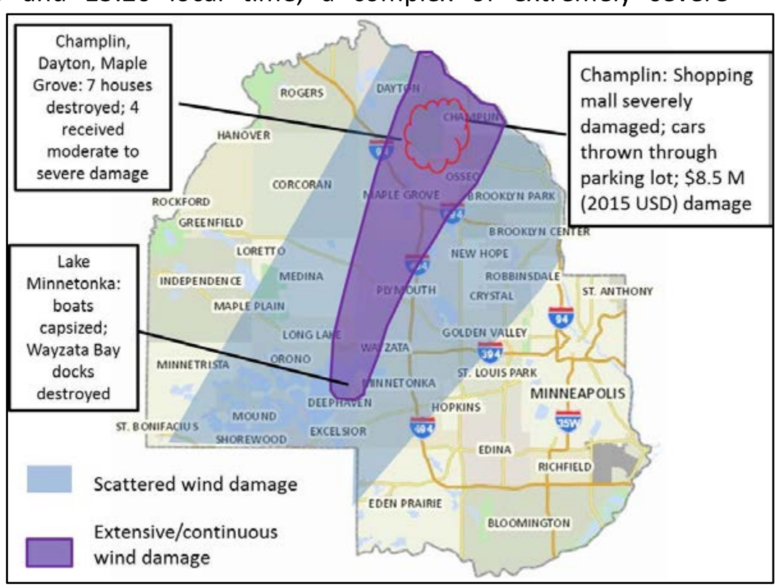


The Independence Day Derecho of 1977

The "Independence Day Derecho of 1977" formed over west central Minnesota on the morning of Monday, July 4th. As the derecho moved east=southeast, it became very intense over central Minnesota around midday. From that time through the afternoon, the derecho produced winds of 80 to more than 100 mph, with areas of extreme damage from central Minnesota into northern Wisconsin.

The derecho continued rapidly southeast across parts of Lower Michigan during the evening, producing winds up to 70 mph and considerable damage before finally weakening over northern Ohio around 1:30 AM on Tuesday, July 5th.

West Metro to Northern Wisconsin Derecho of 1983



On July 3, 1983, between 12:30 and 13:20 local time, a complex of extremely severe thunderstorms affected a southwest to northeast swath of Hennepin County. Damage was most extensive from eastern Lake Minnetonka, through Maple Grove and Champlin. The storms continued into Anoka County, and produced the Twin Cities area's most recent EF-4 tornado in Andover (most recent as of April 2015).

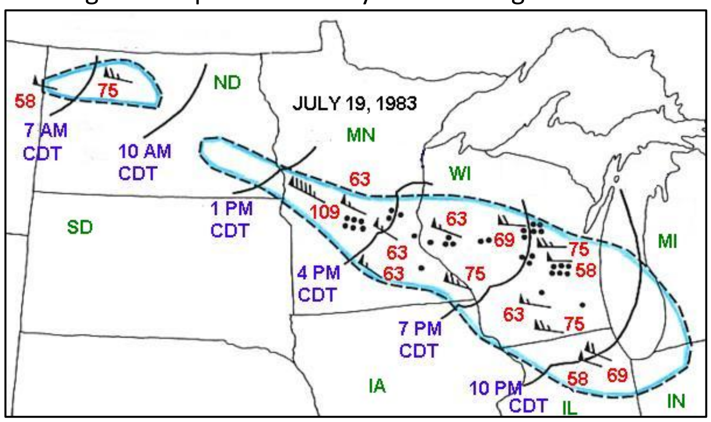
Extreme straight-line winds caused significant damage in a southwest-to-northeast swath across Hennepin County. The storm complex raced northeastward into Wisconsin during the next few hours, and aerial surveys conducted by the University of Chicago found over 150 linear miles of continuous EF-1-equivalent straight-line wind damage, with pockets of EF-2 damage—stretching from Carver County to Ashland, Wisconsin. The National Weather Service Issued "Very Severe Thunderstorm Warnings" for the storm, to indicate winds in excess of 75 mph, and sirens sounded throughout Hennepin County.

This storm remains (as of 2015) the most destructive severe convective storm event in the Twin Cities Metropolitan Area, since the May 6, 1965 tornado outbreak.

The I-94 Derecho of 1983

Around dawn on the morning of Tuesday, July 19, 1983, well north of warm/stationary front over South Dakota and northern Iowa, a bow echo moved out of northeast Montana and began producing damaging winds in northwest North Dakota. This would be the beginning of a noteworthy progressive derecho event that would move across the northern Great Plains and upper Mississippi Valley and reach the Chicago metropolitan area by late evening.

As the convective system's cold pool continued to deepen and elongate east-southeastward with the mean cloud-layer flow, it ultimately reached the warm front as that boundary advanced slowly north across eastern South Dakota and southern Minnesota. This meeting occurred during the early afternoon over west central Minnesota, and likely accounts for the appreciable increase in storm strength observed around that time as the convection became surface-based. At this time the storm system also expanded in scale, evolving into a squall line with two and sometimes three bow echo segments as it continued across Minnesota and later Wisconsin, with Interstate 94 near its central axis.



The path of the 1983 I-94 Derecho as it crossed over six states on July 19, 1983.

Winds over 100 mph were recorded at the airport in Alexandria, Minnesota, Minnesota, where planes and hangers were damaged and destroyed. The storm continued to produce much damage as it moved east-southeast across south central and southeast Minnesota; approximately 250,000 customers lost electrical power in the Minneapolis/St. Paul area.

Thirty-four people were injured in Minnesota and Wisconsin from this storm. Of these injuries, 12 were from mobile homes being blown over, and eight were from falling trees.

Boundary Waters – Canadian Derecho

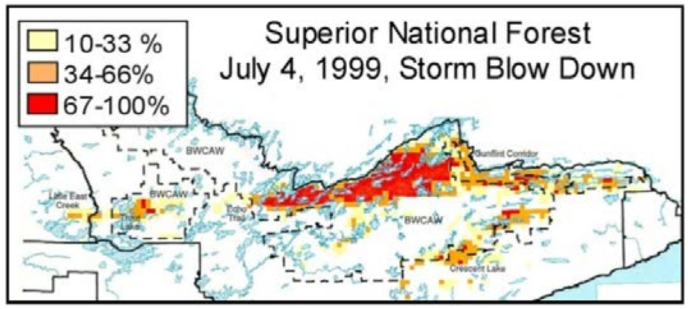
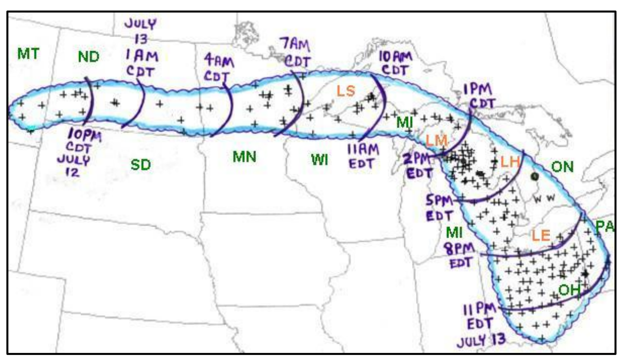


Figure 2. Percentage of trees blown down in Superior National Forest in northeast Minnesota on July 4, 1999. Scale: 1" = 15 miles. (Courtesy of USDA Forest Service, Superior National Forest)

On July 4, 1991 a major derecho in the BWCAW, known as the Boundary Waters-Canadian Derecho, lasted for more than 22 hours, traveled more than 1,300 miles, and produced wind speeds averaging nearly 60 mph. The blowdown caused widespread devastation with casualties both in Canada and the United States. The storm front initiated as large complex of thunderstorms in South Dakota. The storm moved west to east snapping tree trunks in half that pulled power lines down with them in Cass, Crow Wing, Itasca and Aitkin Counties. After blowing down trees on 1,300 acres on the Chippewa National Forest and dropping heavy rains that eroded 9,000 acres of shorelines, the storm continued into northeast Minnesota.

The storm entered the Arrowhead region of northeastern Minnesota in the early afternoon. Here, winds of 80 to 100 mph resulted in injuries to about 60 canoe campers and damage to tens of millions of trees within 477,000 acres of forest land on the Superior National Forest in the course of leveling a swath 30 miles long and 4 to 12 miles wide. The storm affected approximately 477,000 acres (16 percent of the Superior National Forest). The BWCAW sustained the heaviest damage in a line from Ely to the end of the Gunflint Trail.

The Right Turn Derecho of 1995



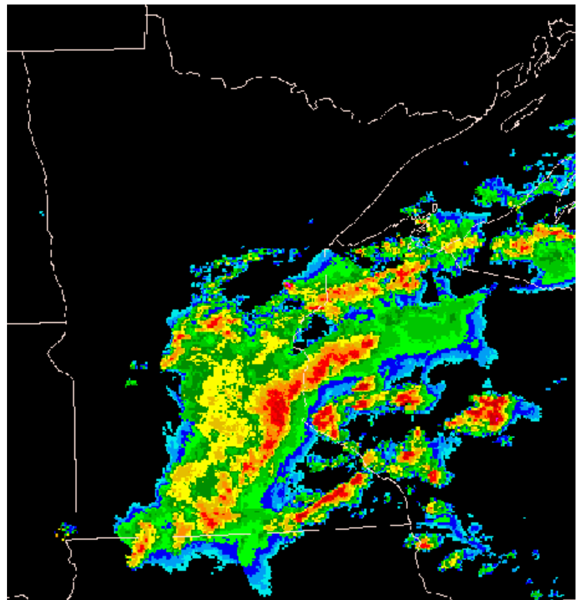
The path of the "Right Turn" Derecho of 1995. One of three derechos to occur on consecutive days across Northern Minnesota.

During the late afternoon of Wednesday, July 12, 1995, thunderstorms formed over southeast Montana and began producing winds that damaged homes and barns. As the storm system moved east across North Dakota, vehicles were overturned and a grain bin was destroyed. Measured winds reached 70 mph at Bismarck. As the system approached Fargo during the early morning of July 13th, it became a well-defined bow echo storm with measured winds of 91 mph at the Fargo airport. The derecho was becoming a "high end" event.

The derecho took a track similar to one of the previous night, producing significant damage for the second night in a row from southeast North Dakota eastward across Minnesota to western Lake Superior. Damage was extreme across Minnesota, with over five million trees blown down and many buildings damaged and some destroyed. Six campers were injured from the falling trees during the pre-dawn hours. Trucks with plows were needed to clear many of the roads, and some areas were without power for a week. Damage totaled well over $30 million in 1995 dollars.

The Southern Great Lakes Derecho of 1998

During the early evening of Saturday, May 30, tornado-producing supercells over eastern South Dakota merged and became a squall line that moved east into southern Minnesota. As the squall line crossed southern Minnesota it evolved into a bow echo system that expanded in scale and raced east across the southern Great Lakes before finally dissipating over central New York after sunrise on Sunday, May 31st. This bow echo system produced one of the most dangerous and costly derecho events in the history of the Great Lakes region. The "Southern Great Lakes Derecho of 1998" adversely affected millions of people on the weekend after Memorial Day. Many casualties and record amounts of damage occurred.



The Southern Great Lakes Derecho as it moved over Hennepin County On Saturday, May 30th.

The bow echo system began to produce significant wind damage over south central Minnesota about 10 p.m. Saturday evening. As the system moved rapidly eastward it grew south into northern Iowa and caused damaging winds over most of southeast Minnesota and northeast Iowa. Many trees and power lines were blown down and several farm buildings were damaged or destroyed.

The most intense damage occurred near the northern end of the bow echo system in Minnesota, from Sibley and McLeod Counties eastward across southern portions of the Minneapolis/St. Paul metropolitan area. Along this band, winds greater than 80 mph were measured; in some areas, estimated speeds reached 100 mph. Tens of thousands of trees were blown down, 500,000 customers lost power, two semi-trailer trucks were overturned, two apartment building roofs were blown off, and 100 boats were destroyed. In addition, over 100 homes were destroyed or badly damaged, and over 2000 others received some damage. Twenty-two people were injured, and damage to property was estimated to be about $48 million in 1998 U.S. dollars...with $35 million dollars of that damage occurring in Dakota County alone.

In summary, while crossing southern Minnesota and northeastern Iowa, the derecho event caused about $50 million in 1998 U.S. dollars of damage, left about 600,000 customers without power, and injured twenty-two people. In some areas, power was not restored until nearly a week after the event.

4.3.3.8. Future trends/likelihood of occurrence

A warmer planet at first glance would appear to be more conducive to the development of the intense thunderstorms that comprise derecho-producing convective systems. But thunderstorm updrafts require the presence of strong vertical temperature gradients; any warming that occurs at the surface likely also would occur aloft. Thus, the net change in instability that is, the net change in the potential for strong updraft development likely would be minimal. In addition, although a warmer environment implies greater atmospheric moisture content and conditional instability (instability related to the release of latent heat during condensation; this is the type of instability that fuels a hurricane), all other factors being equal, the increased moisture also would yield more widespread low-level clouds. Such cloudiness would negatively impact storm initiation and derecho development.

There is nothing to suggest that a warmer world necessarily would favor stronger derechos. This is not only because vertical temperature differences likely would remain unchanged but also because derecho development requires the favorable coexistence of many interacting environmental factors over various scales of time and space. In particular, the small-scale processes involved in the initiation of individual storms and their growth and organization into long-lived mesoscale convective systems are incompletely understood. For this reason these processes are only crudely represented in both short-range (day-to-day forecast) and long-range (climate) numerical models. For example, increased moisture theoretically would be available for cloud and storm development in a warmer world. Increased cloud water content, in turn, generally enhances downdraft strength (through "water loading"). But it does not necessarily follow that storms with water-enhanced downdrafts would be more favorable building-blocks of derechos; if the downdrafts are too strong or ill-timed, their presence could short-circuit derecho development.

What can be said with greater certainty about derechos and climate change is that the corridors of maximum derecho frequency likely would shift poleward with time. This is because the bands of fast upper-level winds that arise from the equator-to-pole temperature gradient --- the **jet stream** would contract poleward in a warmer world. Because derechos tend to form on the equatorward side of jet streams, especially those that mark the northern fringes of warm high-pressure ("fair weather") systems, the areas most favored for derecho development also would shift poleward. It is unclear, however, how jet stream changes might impact derechos from a wind shear perspective. While derechos are not as sensitive to wind shear (changes in wind speed and/or direction with height) as are, for example, tornadoes, some degree of vertical shear is necessary for long-lived derechos. Because the most favorable wind shear environments are tied to the location of the jet stream, it seems reasonable to conclude that, overall, potential changes in shear would not appreciably impact derecho

4.3.3.9. Indications and Forecasting

National responsibility for developing tornado indications and forecasts rests with the National Weather Service's Storm Prediction Center (SPC) in Norman, Oklahoma and the local National Weather Service office in Chanhassen.

4.3.3.10. Critical Values & Thresholds

By definition, winds in a derecho must meet the National Weather Service criterion for severe wind gusts (greater than 57 mph) at most points along the derecho path. But in stronger derechos, winds may exceed 100 mph.

The winds associated with derechos are not constant and may vary considerably along the derecho path, sometimes being below severe limits (57 mph or less), and sometimes being very strong (from 75 mph to greater than 100 mph). This is because the swaths of stronger winds within the general path of a derecho are produced by what are called downbursts**,** and downbursts often occur in irregularly arranged clusters, along with embedded microbursts and burst swaths. Derechos might be said to be made up of families of downburst clusters that extend, by definition, continuously or nearly continuously for at least 240 miles (about 400 km).

4.3.3.11. Preparedness

If planning to be outdoors for a significant length of time, be aware of the weather forecast, especially if you will be well-removed from sturdy shelter. Stay "connected" via television, radio, NOAA Weather Radio, or social media. Derechos rarely occur without warning, although warning lead times may be comparatively limited during the early stages of storm development. Because protracted and extensive electrical and communication disruptions may occur, set aside emergency water and food supplies, can openers, batteries, and flash lights.

4.3.3.12. Mitigation

Education and Awareness Programs

- Educating homeowners on the benefits of wind retrofits such as shutters and hurricane clips.
- Ensuring that school officials are aware of the best area of refuge in school buildings.
- Educating design professionals to include wind mitigation during building design.

Structural Mitigation Projects – Public Buildings & Critical Facilities

- Anchoring roof-mounted heating, ventilation, and air conditioner units
- Purchase backup generators
- Upgrading and maintaining existing lightning protection systems to prevent roof cover damage
- Converting traffic lights to mast arms.

Structural Mitigation Projects – Residential

- Reinforcing garage doors
- Inspecting and retrofitting roofs to adequate standards to provide wind resistance

- Retrofitting with load-path connectors to strengthen the structural frames

4.3.3.13. Recovery

Recovery from derechos can take weeks as power outages from these storms can be extensive. Another consideration when it comes to recovery is the impact to forests, especially logging and the potential for wildland fire due to increased fuel loads. Derechos have even sparked intense political debates at the state and national levels regarding what to do with disturbed forests left in the wake of derechos. Both the “Adirondack” and “Boundary Waters” derechos were responsible for extremely contentious debates on whether salvage logging operations should be permitted in public forests after large blowdowns. In the case of Adirondack Park, salvage operations had been in place for nearly 50 years on the grounds of fire prevention and forest conservation. However, following the assessment of state conservation officers and consulting ecologists, the State of New York enacted to forgo salvaging operations in the Adirondack forest after the derecho. The final assessment concluded that the large forest disturbance produced by the derecho should be treated as a normal ecosystem process.

Hennepin County Emergency Management Capabilities:

- Situation Monitoring Station (SMS)
- Virtual Situation Monitoring Station (VSMS)
- Damage Assessment Teams.

Hennepin County Emergency Plans:

- Hennepin County Emergency Operations Plan

4.3.3.14. References

2007. Mosier, Keith. “After the Blowdown: A Resource Assessment of the Boundary Waters Canoe Area Wilderness, 1999-2003.” United States Department of Agriculture.

2002. Sanders, Jim. “After the Storm. A Progress Report from the Superior National Forest.” United States Department of Agriculture.

January 2013. “NOAA Service Assessment. The Historic Derecho of June 29, 2012.” U.S. Department of Commerce.

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4.3.4.	Hazard Assessment: HAIL

4.3.4.1. Definition

Hail is precipitation that is formed when updrafts in thunderstorms carry raindrops upward into extremely cold areas of the atmosphere where they freeze into balls of ice that eventually become heavy and fall to the ground. Hail can cause billions of dollars of damage to structures, cars, aircraft, and crops, and can be deadly to livestock and people.

Large hail, source NSSL (http://www.nssl.noaa.gov/education/svrwx101/hail/)

Damaging hail is associated with severe thunderstorms, and is often found in proximity to strong winds, torrential rainfall, and even tornadoes.

Supercell thunderstorms are responsible for the majority of Minnesota hail reports in excess of 1.5 inches in diameter, and nearly all reports in excess of 2.5 inches. These supercell thunderstorms may or may not be tornadic at the time of hail production. Damage becomes significantly more likely as hail size increases, because the impact factor increases exponentially with incremental growth **(Table 4.3.4A).**

Table 4.3.4A Hail diameter and impact. From Marshall et al. (2001).

Hail Diameter	1”	2”	3”
Impact (foot-lbs)	<1	22	120

4.3.4.2. Range of magnitude

Largest hail stones reported

- Hennepin:
  - 4-inch diameter, Bloomington, Richfield, South Minneapolis, July 8, 1966
- Adjacent counties:
  - 4.25-inch diameter, New Prague, Scott County, August 24, 2006

    - 4-inch diameter, northern Anoka County, June 14, 1981
    - 4-inch diameter, Zimmerman, Sherburne County, August 27, 1990
- Minnesota:
    - 6-inch diameter, between Edgerton (Pipestone County) and Chandler (Murray County), July 4, 1968
    - 6-inch diameter, near Worthington, Nobles County, July 28, 1986
- US: Record diameter of 8" recorded at Vivian, SD, on July 23, 2010.

Costliest hail event

- May 15, 1998: $950 million USD in 1998 dollars (~1.38 billion in 2015) from damages in Minnesota resulting from hail, straight-line winds, and isolated tornadoes. Vast majority of losses were from wind-driven hail, which destroyed thousands of new and used vehicles, roofs and siding on thousands of homes.

4.3.4.3. Spectrum of consequences

Significant mobile home damage from hail. Source: NSSL

Ultimately, the meteorological environment governs the size of hailstones and dictates the amount of time a given area will be exposed to them. Hail falling in small "popcorn" thunder- storms that form with weak instability and low shear tends to be short-lived and sub severe (less than 1" diameter), although in rare instances can be up to golf ball-sized (1.75"). Hail in fast-moving squall-lines tends to be short-lived and similar in size, although intense winds may turn the hail into dangerous and damaging projectiles. In large and/or slow-moving supercell thunderstorms, hail can fall for up to 30 minutes at a given location, and the high instability and shear producing these storms also often yields golf ball-or-larger hail stones. Although somewhat rare, regenerating supercell thunderstorms may produce multiple hailfalls over a given location in the course of a single event.

Hail over one inch in diameter may produce small "dimples" or "pocks" on vehicle exteriors. At 1.5 inches, damage to roofing materials becomes common. At sizes in excess of 2", windshields and rear windows are often cracked or shattered, vehicle bodies damaged badly, residential windows may be broken, residential siding welted, and many varieties of roofs badly damaged (**Table 4.3.4B**) for an example of roof damage thresholds).

Although fatalities are uncommon, injuries to the head, shoulders, back, and arms are not. Severe bruising, often in multiple locations, is the most typical type of injury. Drivers and passengers of vehicles also may have cuts and lacerations from flying glass.

Table 4.3.4B. Damage onset thresholds for various roofing materials. From Marshall et al. (2002).

Type of Roofing Product (all ages)	Hailstone Size in.	Hailstone Size mm.
3-tab asphalt shingles	1.00	25
30 yr. Laminated shingles	1.25	32
Cedar shingles	1.25	32
Medium cedar shakes	1.50	38
Fiber-cement tiles	1.50	38
Concrete tiles	1.75	44
Built-up gravel roofing	2.50	63

Large hail storms also tend to halt traffic, and may require snow removal equipment to clear area roads. An early morning hail event in November of 1999 caused traffic jams and spinouts in Eden Prairie, and snowplows were needed to clear over 2 inches of accumulated hailstones from I-494. ‘

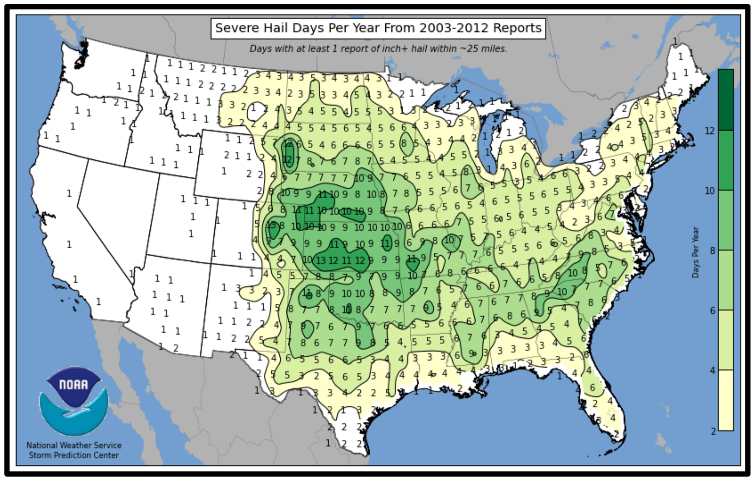
Although the human toll from hail tends to be much lower than from tornadoes and straight-line winds, hailstorms are often costlier, because of the costs associated with cosmetic damages to residences, vehicles, and businesses. Severe crop damage is also common, with soybeans and corn especially susceptible to damages from wind-blown hail. Hail rarely causes infrastructural damage.

4.3.4.4. Potential for cascading effects

The consequences of hail are generally limited to the duration of the hail event, providing few options for cascading effects. However, large and damaging hail events tend to be associated with strong or severe thunderstorms that are producing or are capable of producing other convective weather hazards, which can exacerbate or compound the impacts. The large hail core in a tornado-producing supercell thunderstorm is often very near the tornado itself. Thus hail damage victims are at risk of becoming tornado victims as well. High situational awareness is therefore required during large hail. Any person caught outside during a hailstorm is also at significant risk from excessive rainfall and lightning.

4.3.4.5. Geographic scope of hazard

Minnesota is north and east of the spatial hail frequency maximum within the US, which stretches from southwestern South Dakota, into Nebraska, Kansas, Oklahoma, Colorado and Texas.

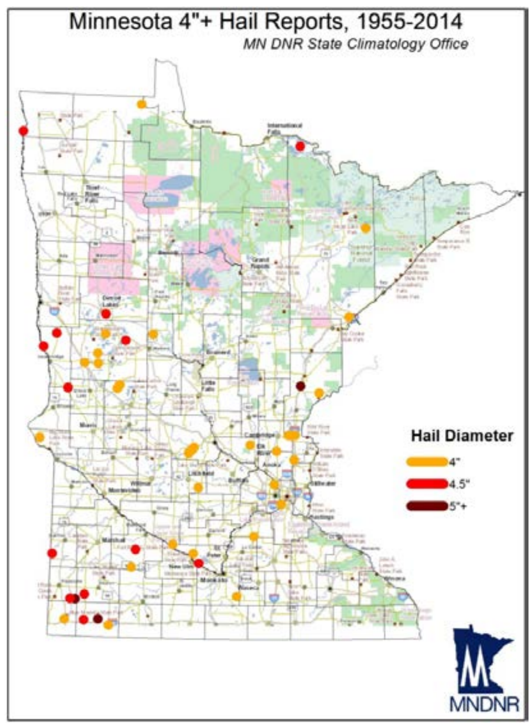


Average number severe hail days, 2003-2012, from Storm Prediction Center WCM Page.

Within Minnesota, hail tends to be most common in the southern and western portions of the state, although large and damaging hail has been observed in every county. The map of all known 4" hail reports since 1955 does show a preference for western and southern Minnesota, but also shows a clustering of reports near the Twin Cities, where more people are available to observe and report hail.

4.3.4.6. Chronologic patterns (seasons, cycles, rhythm)

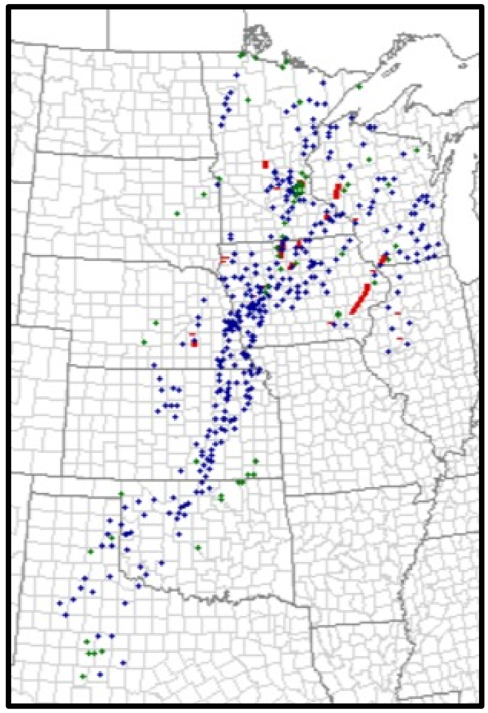
Most years, Hennepin County sees at least one large hail event. The seasonal hail threat coincides with the thunderstorm season, generally from April through September, with a notable peak in frequency in June and July. Severe hail has been reported as early as March in Hennepin County, and as early as February in greater Minnesota. Hail was observed with thunderstorms in the Twin Cities on December 16, 2015, though no damage was observed. Damaging hail in Hennepin County has been reported in November, and has occurred several times during October.



4"+ hail reports in Minnesota, from DNR State Climatology Office

4.3.4.7. Historical (statistical) data/previous occurrence

May 6, 1965*: Most widespread, intense, and long-lasting hail event on record in Twin Cities.* Although May 6, 1965 is best known for its devastating tornadoes in the Twin Cities, the storms also produced destructive hail for an unusually long duration and over an unusually large area. Hail the size of ping pong balls, golf balls, tennis balls and baseballs was reported throughout the evening, in association with both the tornadic storms and the many non-tornadic thunderstorms cells. The largest hail stones were reported in Hennepin County, generally inside what is now the 494-694 corridor. Hail reports were received before the first tornado confirmations, and well after even the last suspected tornado, and the hail event lasted approximately six hours. Many areas were hit by tornadoes early in the evening, and destructive hail later in the evening, and some locations were hit by three distinct waves of hail larger than golf balls. Locations in Hennepin County reporting golf ball or larger hail include Minneapolis, east Bloomington, west Bloomington, St. Louis Park, New Hope, Brooklyn Center, Maple Grove, Brooklyn Park, Edina, Deephaven, Crystal, and Eden Prairie.

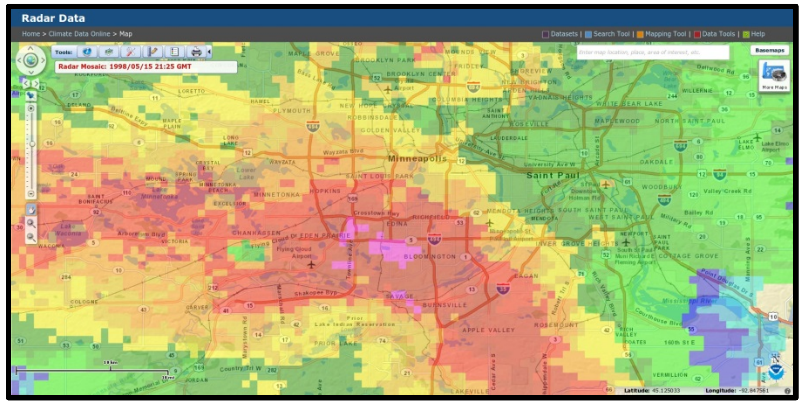


Wind (blue), hail (green), and tornadoes (red) reported on May 15, 1998. Generated from Severe Plot 3.0 (see references).

May 15, 1998*: derecho hailstorm*

A severe squall line developed in western Texas around midnight and raced northeastward, making it to south-central Kansas by daybreak, southwestern Iowa by mid-morning, and the Twin Cities area by 16:00 local time. The storms produced widespread damaging wind along the 1000-mile-long track, and reached peak intensity in Iowa, Minnesota, and Wisconsin, with fast-moving tornadoes and 1-2” hail driven by 60-80 mph winds.

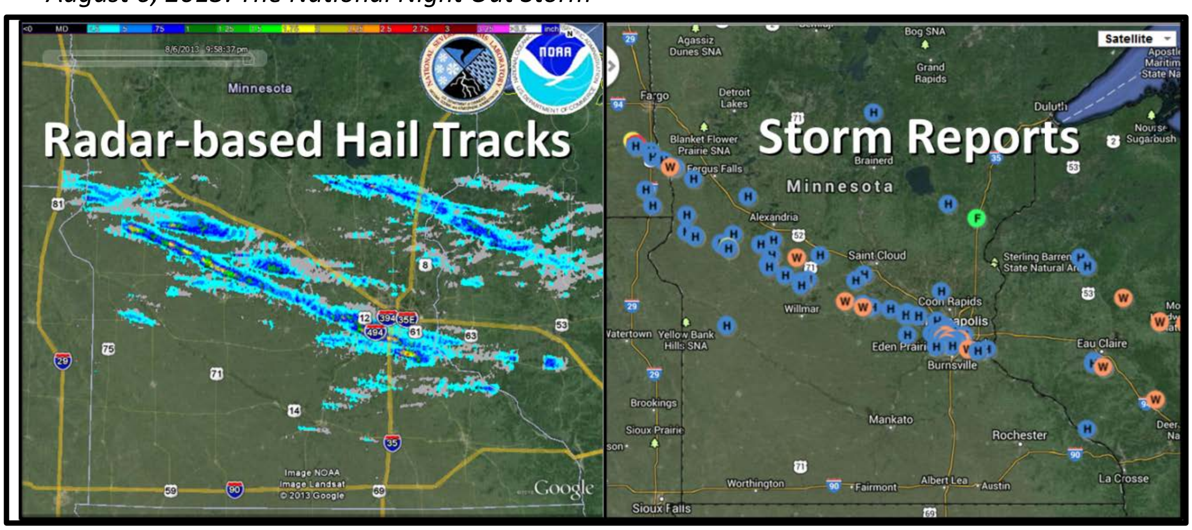
The storms produced a record number of power outages in Minnesota (the record has since been broken twice), and snapped or uprooted hundreds of trees in Hennepin County alone (with estimates of over 1000 trees killed in Ramsey County). A tornado tracked from Roseville into Blaine, at an estimated speed of 80 mph, causing significant damage to homes. The majority of the damages, however were from the hail, which broke windows, damaged roofs, bent garage doors, and forced automobile dealerships in Bloomington to submit claims for their entire outdoor inventories.



Radar at 16:25 local, as bowing hail core entered central Twin Cities

The largest hail reported in the Twin Cities was 2 inches, and the vast majority of reports were in the 1-1.5” range. However, the intense straight-line winds turned the hail into dangerous projectiles, and produced far more damage than would normally be expected.

August 6, 2013: The National Night Out Storm



Radar and report-based hail tracks. Source Minnesota State Climatology Office

On an evening when many Minnesotans were outside at neighborhood block parties, a powerful supercell thunderstorm moved across central Minnesota into western Wisconsin, producing a large swath of severe weather. Most reports were concentrated just south of the I-94 corridor, and the storm caused extensive damage to crops and vehicles.

The National Night Out storm had less wind but somewhat larger hail than the May 15 1998 storm. Winds were generally confined to 65 mph or less, but hail sizes were typically 1.5 - 2 inches in the core of the storm, which covered the southwestern third of Hennepin County. Damage to roofs and vehicles was common from Maple Plain, through the Lake Minnetonka area, into Eden Prairie and Bloomington. Damages were not quantified locally, but Aon-Benfield counted $1.25 billion in damages from storms over the northern and central US on August 5-7, noting that Minnesota and Wisconsin were hardest-hit.

Damage to squad car. Image courtesy Eden Prairie Police Department

4.3.4.8. Future trends/likelihood of occurrence

Research into hail frequencies in a changing climate has been somewhat limited, though modelling efforts have suggested that the frequency of hail may decrease at the expense of more days with straight-line winds, because the atmosphere will favor higher instability but lower-shear profiles as the equator-to-pole temperature gradients weaken (Brooks 2013). Other research has suggested there may be fewer hail days, but more significant events on the days with hail. The bottom line is that hailstorms, some significant, should be expected into the future.

4.3.4.9. Indications and Forecasting

Like other severe weather hazards, national responsibility for hail monitoring and forecasting lies with the National Weather Service's Storm Prediction Center (SPC) in Norman, Oklahoma. The SPC uses three different "products" that detail in anticipation of a severe weather event:

Convective Outlooks are spatial products that assign risk categories for severe weather, and quantify the varying risk for hail (and other hazards) each day, along with an explanation of the basis for the risk categories assigned. Outlooks are issued for Day 1 (day of), and days 2-8. Only

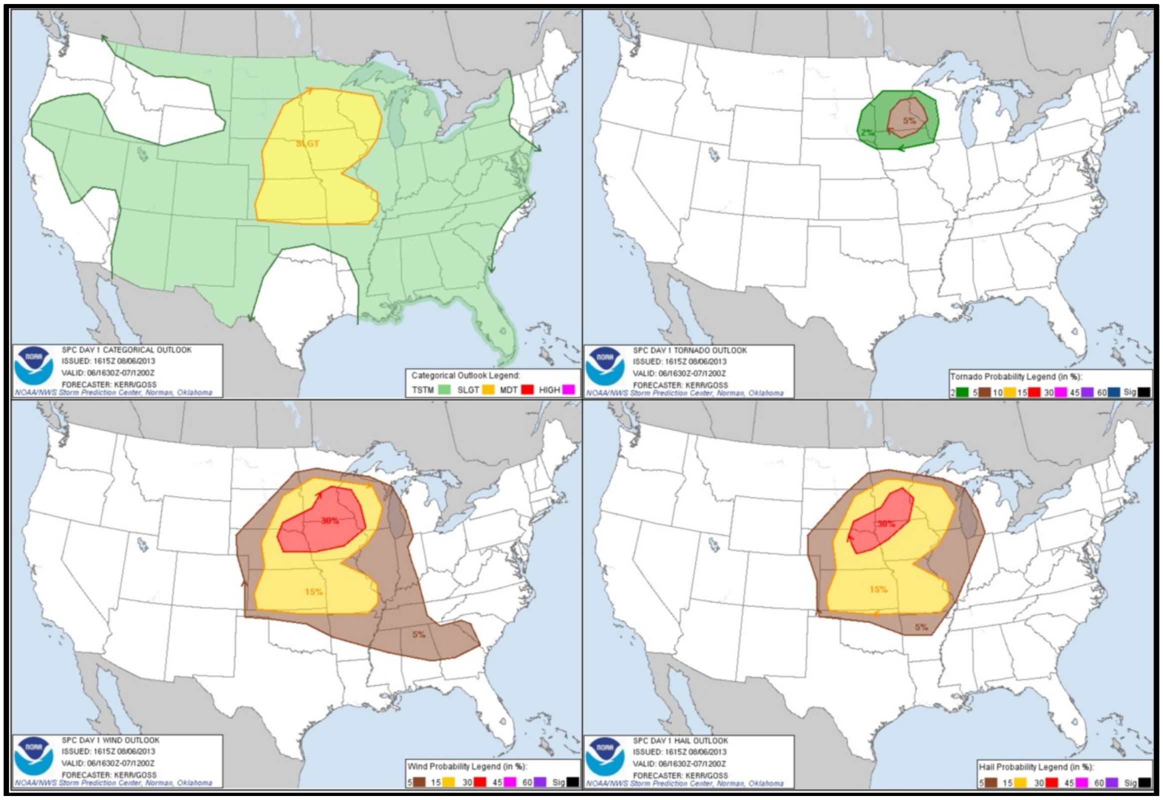
Day-1 outlooks contain hail-specific probabilities. “Day 1” outlooks are issued at 01:00, 08:00, 11:30, 15:00 and 20:00 (all times CDT). For Day 1, risk categories include Marginal, Slight, Enhanced, Moderate, and High. These risk categories are assigned based on the probabilities of severe weather (or a particular hazard) occurring with 25 miles of a point. (As shown in **Table 4.3.4C**)

Table 4.3.4C

Day 1 Outlook Probability	TORN	WIND	HAIL
2%	MRGL	Not Used	Not Used
5%	SLGT	MRGL	MRGL
10%	ENH	Not Used	Not Used
10% with Significant Severe	ENH	Not Used	Not Used
15%	ENH	SLGT	SLGT
15% with Significant Severe	MDT	SLGT	SLGT
30%	MDT	ENH	ENH
30% with Significant Severe	HIGH	ENH	ENH
45%	HIGH	ENH	ENH
45% with Significant Severe	HIGH	MDT	MDT
60%	HIGH	MDT	MDT
60% with Significant Severe	HIGH	HIGH	MDT

SPC probabilistic risk table with corresponding outlook categories

Risk categories and probabilities are displayed on maps as color contours. The image below shows the slight risk and probabilities of specific hazards at the 15:00 CDT outlook, just hours ahead of the National Night Out storm.

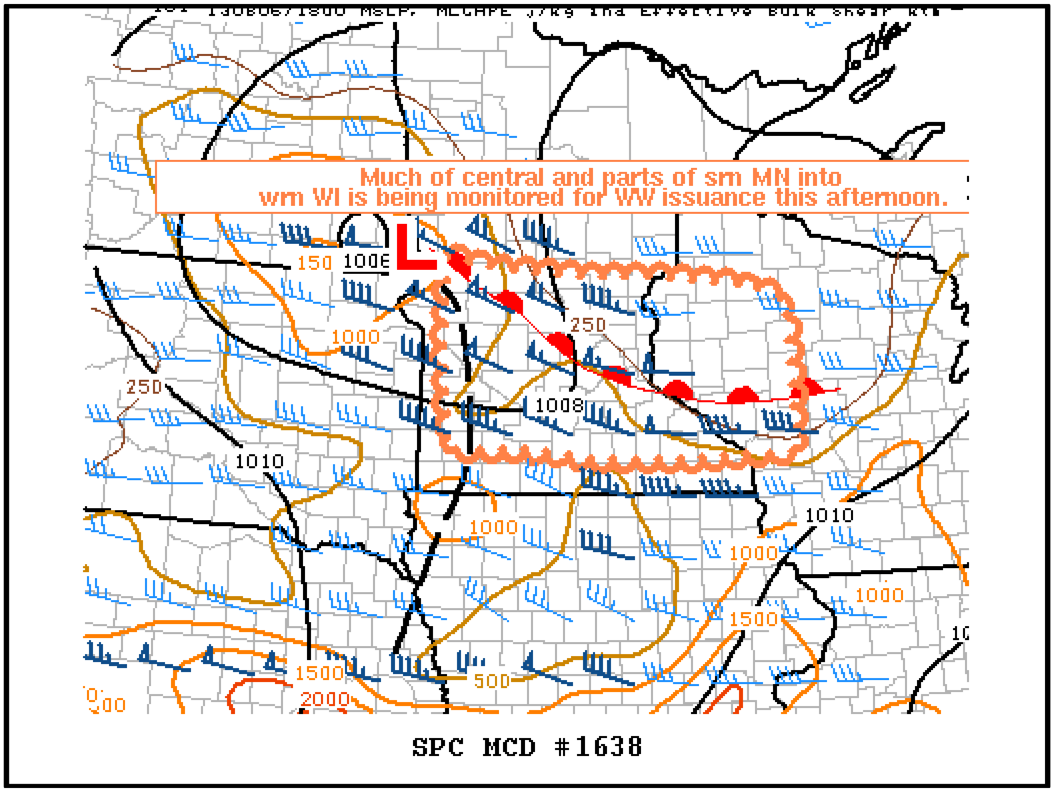


Convective outlook (upper left), tornado (upper right), severe wind (lower left), and hail probabilities on august 6, 2013. From SPC's severe weather events database.

Mesoscale Discussions (MDs) are used to identify a particular area of concern within a risk area, often when storms have developed or are expected to, and to communicate the possibility that a watch may be issued. The MD will be tagged with a statement of likelihood regarding the issuance of a Watch, as follows:

Severe Potential…Watch Unlikely (5 or 20%)
Severe Potential…Watch Possible (40 or 60%)
Severe Potential…Watch likely (80 or 95%)
Severe Potential…Watch Needed Soon (95%)

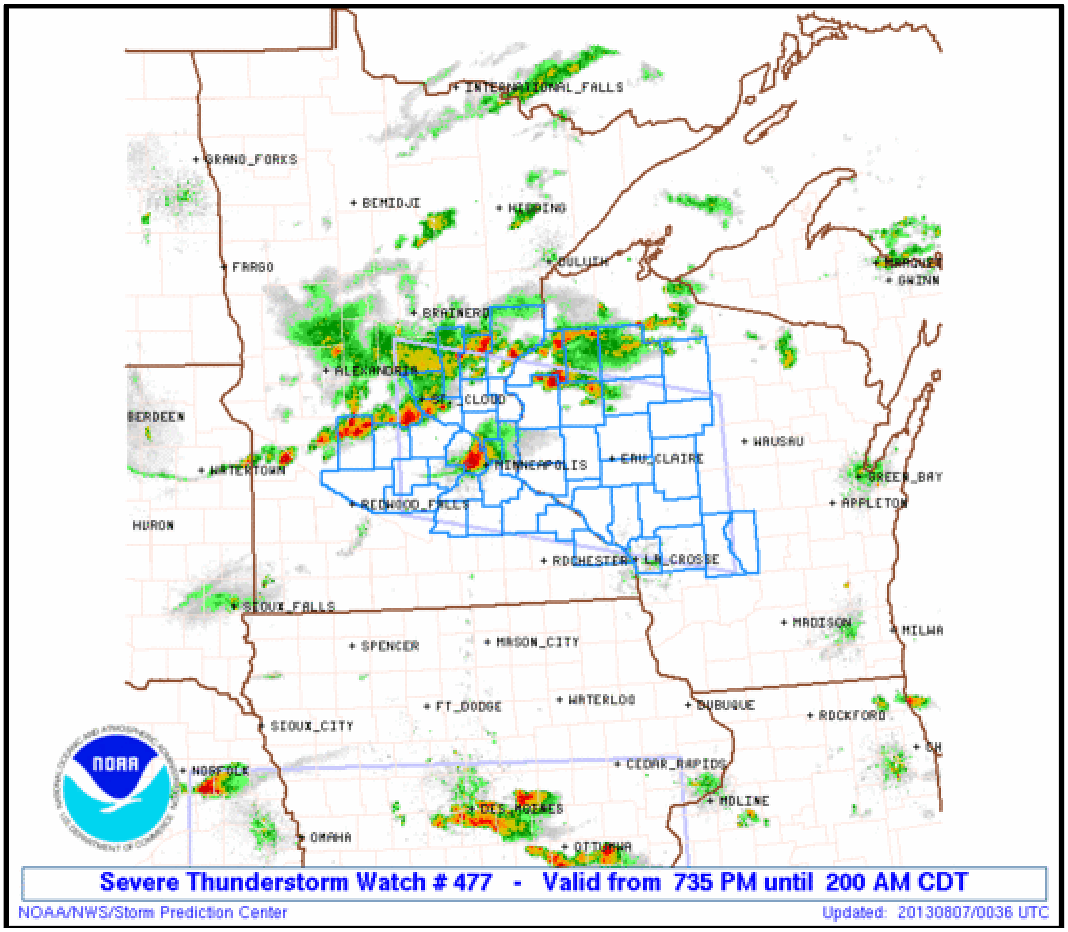
MDs can also be used to communicate additional concerns or trends during an ongoing event. Like Convective Outlooks, MDs are both graphical and textual. The following MD graphic was issued after the 15:00 CDT Convective Outlook, in anticipation of a watch issuance.



Mesoscale Discussion graphic issued in anticipation of National Night Out severe weather event

Watches are issued when atmospheric conditions are favorable for the development of severe weather. They are more geographically specific than Convective Outlooks, and they have defined geographic boundaries, as well as start and end times. Typically, a watch will cover about 50,000 square miles--slightly more than half the size of Minnesota--and will last between 5 and 8 hours. Tornado watches are used when conditions favor development of tornadoes, in addition to other forms of severe weather. Severe thunderstorm watches are used when the tornado risk is relatively low hail and/or strong winds are expected. Large hail can be expected with both types of watches, and neither connotes a greater or lesser risk of hail.

The National Night Out hail even was initially covered by a Tornado Watch, which was replaced by a Severe Thunderstorm Watch after a few hours, when it became apparent there was not enough low-level moisture or shear to produce tornadoes, but plenty instability aloft and mid-level shear to produce large hail and strong winds. Below is the Severe Thunderstorm Watch outline with radar overlay.



Severe thunderstorm Watch outline with radar overlay on August 6, 2013

In addition to the SPC's information and products, the local National Weather Service Forecast Office issues a Hazardous Weather Outlook (HWO), generally 1-2 times per day, as situations warrant, to share thoughts about the potential for severe weather, including hail. These outlooks often discuss likely timing and locations.

4.3.4.10. Detection & Warning

Local responsibility for detecting and warning citizens about severe hail lies with the National Weather Service forecast office in Chanhassen. The primary means to communicate urgent storm location and timing information is through the use of Severe Thunderstorm and Tornado Warnings. These warnings indicate that severe weather is imminent, and will be affecting the warned area for a specified period of time. As with watches, hail can be expected in both Severe Thunderstorm and Tornado Warnings, and neither is a better indicator than the other of hail risk.

The NWS uses a combination of trained spotters and radar to detect severe hail. NWS Chanhassen has access to two RADAR sites for remote monitoring of hail-containing storms--the NEXRAD WSR-88D in Chanhassen, and the Terminal radar located in Woodbury. Numerous tools and algorithms enable NWS staff in Chanhassen to use these radar systems for identification of severe hail in thunderstorms.
Spotter reports, reports from emergency managers, and increasingly, reports from social media also help forecasters in Chanhassen assess the severity of ongoing storms.

4.3.4.11. Critical values and thresholds

The National Weather Service considers hail to be severe if it equals or exceeds one inch in diameter. Because impact increases exponentially with incremental increases in hail size, larger hailstones pose a significantly greater risk to safety and property. Therefore, spotters are trained to use common objects to make estimates about the size of hailstones. It should be noted that few hailstones are ever measured. Instead, they are often observed, compared to the common objects, and then the size is inferred from the size of the stated objects. Thus, reported hail sizes are almost always crude estimates. **Table 4.3.4D** summarizes the common objects used as hail size references, along with the approximate diameter. The diameters, and often not the common objects, will be preserved in the Storm Events Database.

Table 4.3.4D

Hailstone size	Measurement		Updraft Speed	
	in.	cm.	mph	km/h
bb	< 1/4	< 0.64	< 24	< 39
pea	1/4	0.64	24	39
marble	1/2	1.3	35	56
dime	7/10	1.8	38	61
penny	3/4	1.9	40	64
nickel	7/8	2.2	46	74
quarter	1	2.5	49	79
half dollar	1 1/4	3.2	54	87
walnut	1 1/2	3.8	60	97
golf ball	1 3/4	4.4	64	103
hen egg	2	5.1	69	111
tennis ball	2 1/2	6.4	77	124
baseball	2 3/4	7.0	81	130
tea cup	3	7.6	84	135
grapefruit	4	10.1	98	158
softball	4 1/2	11.4	103	166

Hailstone size comparisons of commonly reported reference objects.

4.3.4.12. Prevention

Hailstorms cannot at present be prevented and should be considered an occasional risk within Hennepin County. There, are however, ways to mitigate risks to life and safety from hail.

4.3.4.13. Mitigation

The risks of being killed or injured by hail are greatest when hail is very large and/or wind-driven. Thus, awareness of conditions that could lead to severe weather and hail, and having a plan of retreat if storms approach is of primary importance.

As with all storms, the safest place to be when it’s hailing is inside, in a sturdy structure, away from windows. Even though cars often lose windows and contain some flying glass, they may be safer than being outside, if the travel distance to the vehicle is reasonable. If no shelter or vehicle is available, retreat to lower ground if possible, stay away from trees, which pose a lightning risk, and cover the head by all means possible to avoid potentially lethal impacts from large hail.

On the road, many drivers make choices that ultimately compromise the safety of other motorists. Driving into hail at highway speeds increases a hailstone's momentum (and therefore impact) substantially. Thus, if it begins hailing while driving, look for potentially shelter options off the road, and slow down and look for potential shelter options off the road. There may be none, but slowing down will reduce the impact of hail to the vehicle, reducing the risk for damage, and potential injury from shattered glass. If slowing down does not adequately reduce the risks, pull completely off the road and stop. Stopping in an active traffic lane forces all drivers behind you to stop also. This can be particularly dangerous if a tornado is associated with the storm because the tornado and the hail may be very close to one another.

4.3.4.14. References

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Storm Prediction Center (SPC), *Storm Prediction Center WCM Page,* http://www.spc.noaa.gov/wcm/

4.3.5.	Hazard Assessment: LIGHTNING

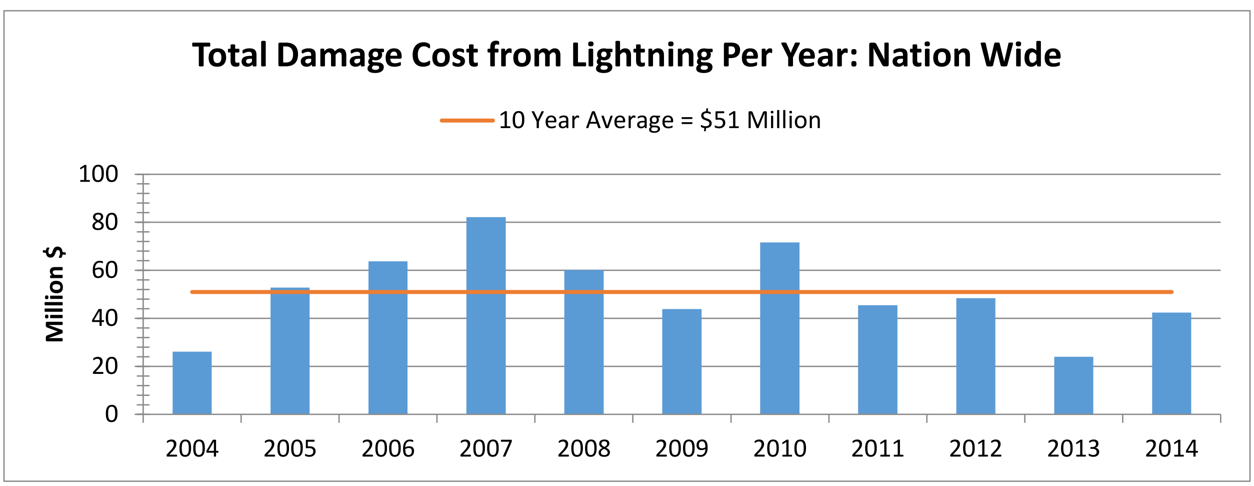
4.3.5.1. Definition

Lightning is one of the oldest observed natural phenomena on earth. It has been seen in volcanic eruptions, extremely intense forest fires, surface nuclear detonations, heavy snowstorms, in large hurricanes, and most commonly, thunderstorms. Lightning is essentially an electrical current where electrostatic discharges between the cloud and the ground, other clouds, or within a cloud. Within a thunderstorm, many small bits of ice (frozen raindrops) bump into each other as they move around in the air. All of those collisions create an electric charge. The positive charges, or protons, form at the top of the cloud and the negative charges, or electrons, form at the bottom of the cloud. Since opposites attract, that causes a positive charge to build up on the ground beneath the cloud. The ground's electrical charge concentrates around anything that sticks up, such as tall buildings, people, or trees. The positive charge coming up from these points eventually connects with the negative charge reaching down from the clouds, and that is when you see the lightning strike.

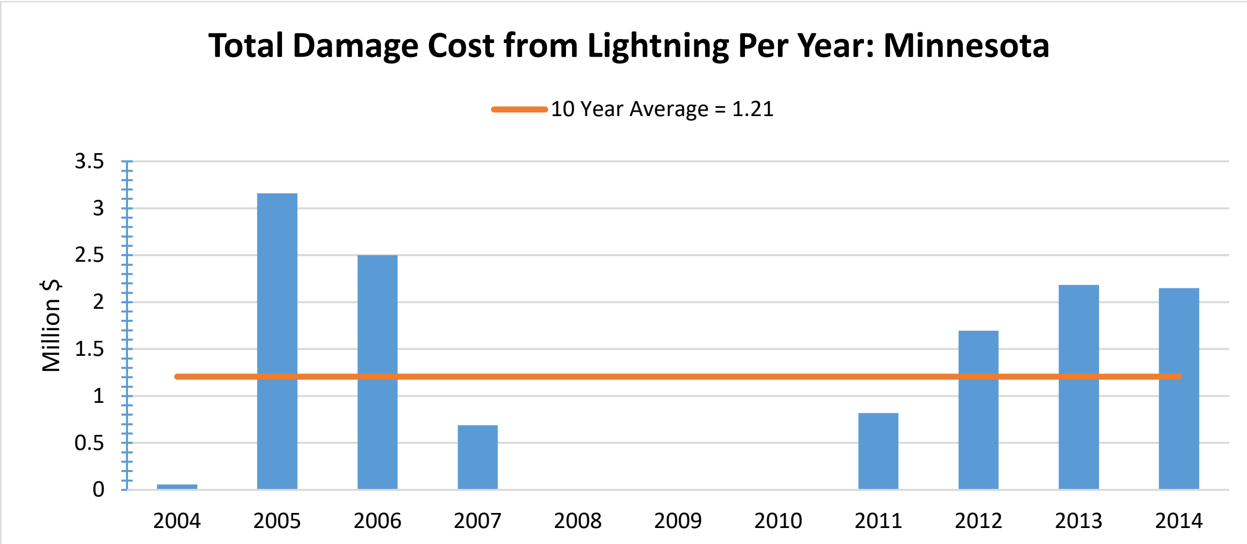
4.3.5.2. Range of Magnitude

The magnitude of lightning is incredibly variable from storm to storm. Typically when discussing magnitude of lighting, one is concerned mostly with lighting strikes that hit the ground. **GRAPHICS 4.3.5A and 4.3.5B** are using data from the National Climatic Data Center, which show the reported costs from lightning for the past 10 years.

GRAPHIC 4.3.5A



GRAPHIC 4.3.5B



4.3.5.3. Spectrum of Consequences

Lightning strikes are the leading causes of wildfires, and have been responsible in the past for some of the most devastating fires in the southwest United States. According to Storm Data, Minnesota ranks 28th in the United States in lightning deaths from 1959-2012. Lightning is not only a threat to public safety, but also a threat for public and private structures because of the large amount of structural fires started from lightning each year. Lightning can have direct and indirect effect, depending on whether it strikes a structure directly or not. The effects depend greatly on the conductivity of the materials the electricity travels through.

Material	Consequence
Electrical	Electrical voltages created by electrical discharges dissipated in the ground that is struck by lightning.
Thermal	Substantial damage and injuries from fires, burns, and destruction caused by a major release of heat.
Electrodynamic	Forces of attraction occur between parallel conductors that are traversed by currents in the same direction create mechanical stresses and strain.
Electromagnetic	The lightning current induces extremely high voltage and an extremely strong electromagnetic field that generate very powerful electric pulses that can damage sensitive electronic devices.

Electrochemical	Corrosion due to currents circulating through buried conductors
Acoustic (Thunder and Pressure Waves)	Window panes can be shattered a few meters from the point of impact.
Physiological	From simple dazzling to being struck dead by lightning, with a range of effects in between: Nervous shocks, various forms of blindness, deafness, blacking out, and momentary or prolonged comas.

A common misconception of people being killed from lightning is because they were struck. In actuality, the vast majority of lightning injuries and deaths are causes by mechanisms other than direct lightning strikes. Only 3-5% of lightning strike victims actually take a direct strike. 3-5% of lightning victims are contact injuries where the person is touching or holding an object to which lightning attaches, such as indoor wired telephones or plumbing that transmits current to the person. 30-35% of injuries are caused by a side flash, also called splash. Side flashes occur when lightning hits an object such as tree or building and travels partly down that object before a portion jumps to a nearby victim. The majority of injury (50-55%) come from ground current. Ground current arises because the earth is not a perfect conductor. Ground current effects are more likely to be temporary, slight, and less likely to produce fatalities. However multiple victims and injuries are more frequent from ground current. Another 10-15% of injury occur from upward leaders. Upward leaders are upward discharges of lightning, which almost always occur from towers, tall buildings, or mountain tops.

A direct consequence to the body is an intense shock can severe impair most of the body's vital functions. Cardiac arrest is common. Commonly when there is a strike that affects the heart directly, there is a massive shutdown. With every beat the heart depolarizes and changes its electrical signal. In addition, people can develop problems days, weeks, or months after being struck or being close to a lightning strike.

4.3.5.4. Potential for Cascading Effects

Lightning strikes that hit the ground, called cloud to ground strikes, can have a vast array of consequences. One of the most common cascading events is when a lightning strike causes a fire to start, which can then spread to homes, or produce wildland fire. Another consequence would be if lightning strikes a transformer and people are without power for days, those people could be at risk for heat illnesses if hot and humid conditions persist bringing high heat indices.

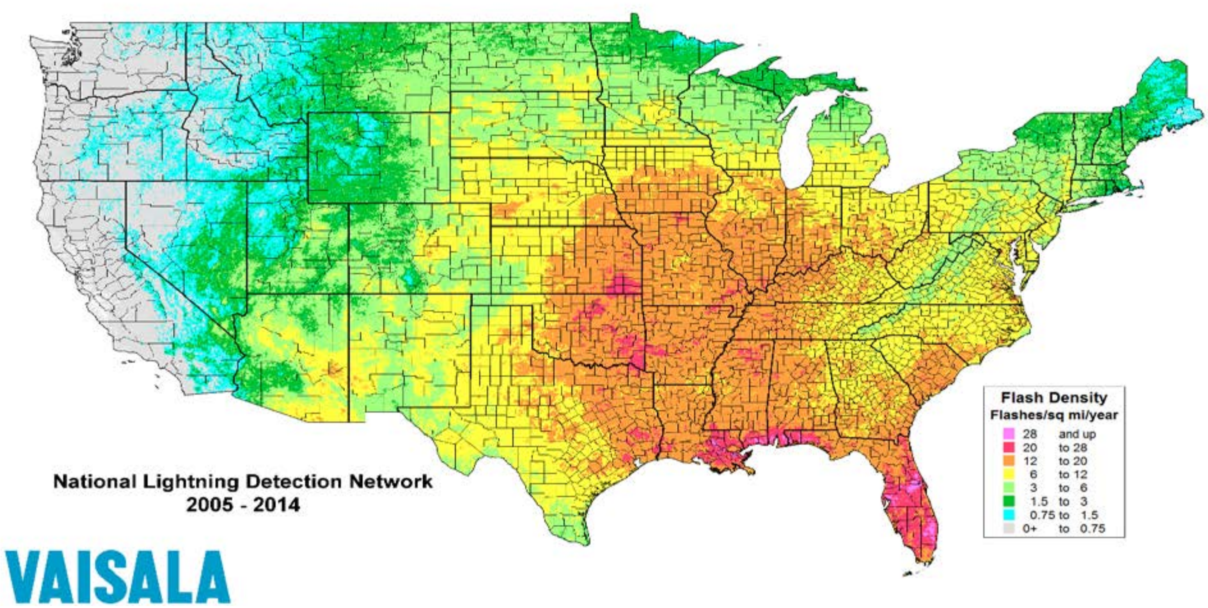
When lightning strikes a building, transients are generated on adjacent power, data, telephone and/or RF lines. As these transients pass through electronic equipment on their way to earth, they can cause both immediate damage or longer term component degradation. However, the problem goes far beyond a direct strike. Today our electronic systems are intrinsically connected to the outside world; not only by mains power cables, but also through data and telephone lines, RF feeders, etc. Transient over voltages from lightning activity up to 1 km away can destroy equipment inside a building, even when the building itself has not been struck. As transients can be induced onto any conductive cable-overhead or underground, the power, data, telephone or RF lines leaving a building to join the main network or even running between buildings can provide a way in for transients looking for a path to earth. Lightning simply striking the ground, or even cloud-to-cloud lightning, induces a transient overvoltage on those cables, allowing access directly into the electronic heart of that theoretically protected building. The following is a list of possible secondary consequences following a lightning event.

- Downtime and disruption
- Hardware damage
- Software corruption
- Data loss
- Lost production

4.3.5.5. Geographic Scope of Hazard

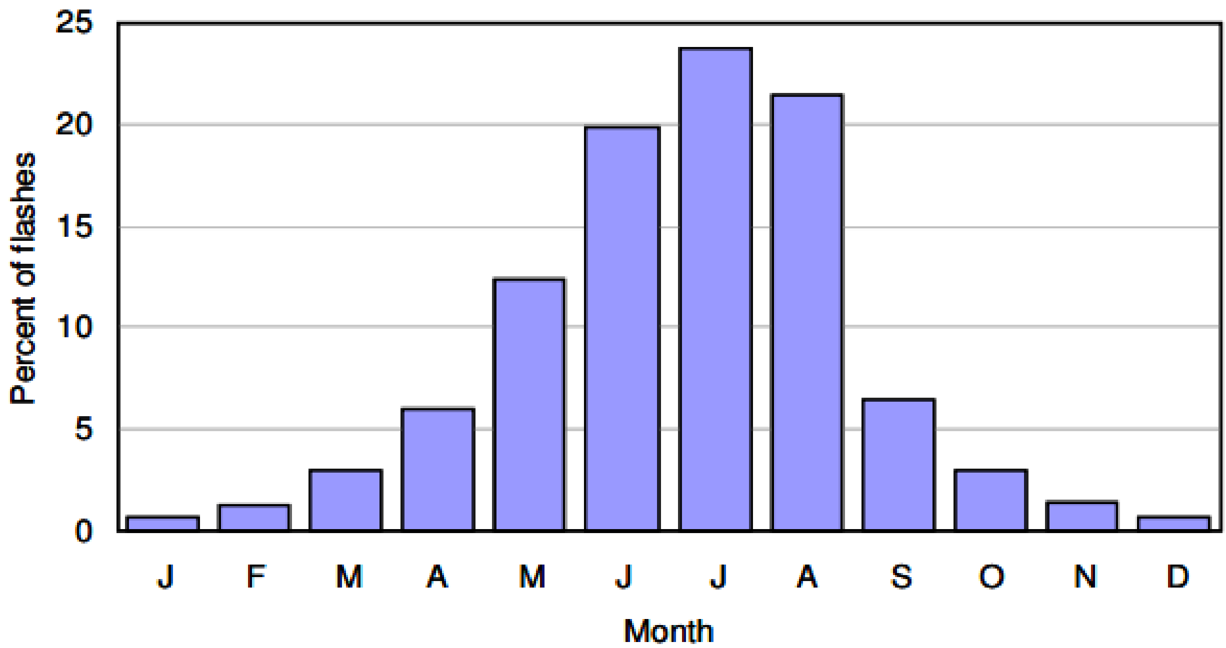
As mentioned, lightning is one of the oldest observed natural phenomena on earth and has been seen in many different types of natural phenomena. This means lightning occurs all across the world, United States, and of course, Minnesota. Individual lightning strikes are relatively small in geographic scope. However, when an area has a storm filled with lightning, or multiple storms filled with lightning, you can have a large geographic area being affected all at the same time. **Graphic 4.3.5C** shows Flash Density map from Vaisala which shows the flashes per square mile per year for the entire United States.

Graphic 4.3.5C



4.3.5.6. Chronologic Patterns

Lightning can happen any time of year, however it is more prominent with spring and summer months as this is when the majority of convective weather occurs.

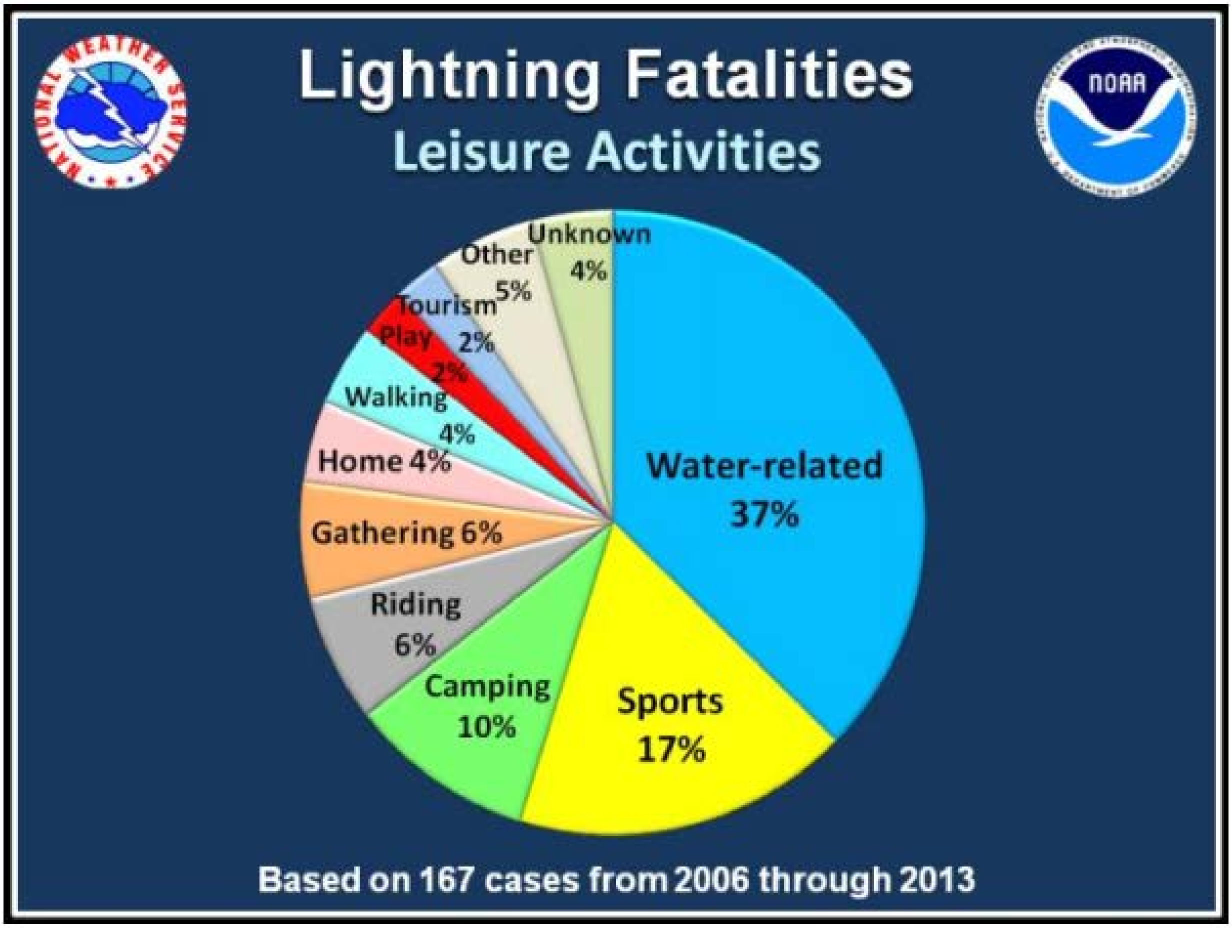


4.3.5.7. Historical Data

Lightning is a usual occurrence in thunderstorms across the State and Hennepin County each year. Every year, about four percent of Minnesota structural fires are caused by natural events, one can infer these natural events to be lightning related. The National Climatic Data Center states that there have been $700,000 dollars in damage and 6 injuries due to lightning strikes in Hennepin County since August of 1995. From 1959-2014, Minnesota has had 64 lightning fatalities in the state.

Historically, data shows us that leisure-related activities are the greatest source of lightning fatalities. From a study that looked at lightning deaths from 2006 through 2013, fishing contributed to the most lightning deaths with 11% of all deaths. Please see **GRAPHIC 4.3.5D** for the top 11 activities that contributed most the lightning deaths during this period. This is consistent with a study that was published in 1999 that looked at lightning casualties and damages from 1959 to 1994 in the United States.

GRAPHIC 4.3.5D Lightning Fatalities



4.3.5.8. Future Trends

Some studies have shown changes in lightning associated with seasonal or year-to-year variations in temperature, but there have not been any reliable studies conducted to indicate future trends of occurrence until recently. A study looked at two variables, precipitation and cloud buoyancy and how they might be a predictor of lightning (see more in the indications and forecasting section for predicting and forecasting lightning). The scientists found that on average, climate models predict a 12 percent rise in cloud-to-ground lightning strikes per temperature degree increase in the contiguous U.S. This is roughly a 50 percent increase by year 2100 if earth continues to see the expected seven degree Fahrenheit increase in temperature. While this is a step into looking into the future trends of lightning as our climate continues to change, less is known about the exact locations on where strikes will increase.

4.3.5.9. Indications and Forecasting

"Lightning is caused by the charge separation within clouds, and to maximize separation, you have to lift more water vapor and heavy ice particles into the atmosphere" (Romps, 2014). It is known that the faster the updrafts, the more lighting, in addition, the more precipitation, the more lighting. How fast the updraft of the convective clouds are determined by the convective available potential energy (CAPE) which is measured by radiosondes, balloon-borne instruments, released by each weather forecast office (WFO) twice a day. CAPE is essentially how potentially explosive the atmosphere is. In essence, where forecasters see high CAPE values, and high water vapor content in the atmosphere is where expected lightning and thunderstorms are to occur.

4.3.5.10. Detection & Warning

Currently, there are no official alert or warning products that are issued by the National Weather Service for just lightning. There are, however, certain programs that can be used that have lightning detection. One of the leading lightning detection companies across the United States is Vaisala. Vaisala's Global Lightning Dataset was first launched in September 2009. However, currently there is no way to receive lightning detection data from Vaisala, or other detection sources, without a paid subscription to a specific service. There are also very few, if any, sources that will give you the distinction between cloud to ground lightning and intra-cloud and cloud to cloud lightning, partly because the science is just starting understand how to detect the difference.

4.3.5.11. Critical Values and Thresholds

Although there are not watches or warnings for lightning, by using the detection services that available, one can watch how lighting within a storm is changing. In general, if lightning activity is increasing within a storm, one can infer that the storm is strengthening. If lighting activity is decreasing, one can infer that the storm is weakening.

4.3.5.12. Prevention

You cannot prevent lightning from occurring, but you can prevent some of the consequences by being aware of when thunderstorms are forecasted as well as being aware of the potential cascading consequences that can accompany the lightning.

4.3.5.13. Mitigation

While there is no way to prevent lightning from happening, there are mitigation strategies to help protect from the effects of lightning. First is protecting critical facilities and equipment by installing protection devices such as lightning rods and grounding on communications infrastructure, electronic equipment, and other critical facilities. Another way to mitigate for lightning is through educational and awareness programs. Developing brochures to hand out at festivals, or with monthly water bills is one of the popular strategies. Additionally, teaching schoolchildren about the dangers of lightning and how to take safety precautions is another way to reach the parents at home as well.

4.3.5.14. Response

Quick response when it comes to effects from lightning is crucial. When someone is struck or is affected by a near strike, ground current, first aid and CPR is crucial. However, CPR must continue for a long time because it takes a long time for the heart to beat again, the diaphragm to function, and even longer for the brain to reboot and control vital organ functions. People who go into cardiac arrest from lightning have a 75 percent mortality rate. Quick response is also needed when lighting causes a fire. Whether it is a structure fire or grass/wildland fire, the more spread, the more damage. Please see the Wildland Fire section of this hazard assessment for more information about response.

4.3.5.15. Recovery

Assessing the damage is the first part of the recovery process. People who are victims of a strike or near strike ay not ever fully recovery and may continue to have issues the rest of their lives. However, the faster the treatment they can get immediately, the faster recovery they will see.

4.3.5.16. References

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4.3.6.	Hazard Assessment: RAINFALL, EXTREME

4.3.6.1. Definition

Extreme rainfall leads to flash flooding, infrastructural and property damage, and even loss of life. Although the definition varies by application, extreme rainfall events are generally understood to have rates that meet or exceed a given threshold, often tied to storage or drainage capacity.

Cars stranded on I-35 in south Minneapolis after excessive 1-hour rains fell on July 1, 1997.

Virtually all extreme rainfall events in Minnesota are associated with thunderstorms. Short-duration extreme events, in which an unusually large quantity of rain falls in a short amount of time (for example, 3 inches falling in one hour) are often associated with severe supercell thunderstorms, squall lines, and mesoscale convective systems. Long-duration events in excess of six hours tend to occur in environments favorable for strong thunderstorms, but not favorable for sustained severe weather. In these situations, there is often a stationary boundary allowing regenerating thunderstorms to pass over the same locations, in a process known as “training.”

In forecasting applications, extreme rainfall drives the issuance of National Weather Service flash-flood products based on “flash-flood guidance,” which is a changing, location-dependent value that utilizes pre-existing soil moisture and land cover conditions. Unsaturated soils and ample vegetation require higher precipitation rates to trigger flash-flooding than saturated soils, denuded vegetation, or impervious surfaces.

Extreme rainfall also is critical to hydrologic design of roads, trails, culverts, retention and detention ponds, dams, and other types of infrastructure. Engineers and planners design these facilities to withstand all but some small percentage of all heavy rainfall events. For instance, many non-critical features like small roads and trails are designed to withstand a storm that has a 10% probability in any given year (also known as the 10-year storm). More critical features will often be designed for 100-year rainfall events--those that have a 1% probability in any given year. NOAA Atlas 14 contains the most recent scientific estimates of rainfall amounts for durations from 5 minutes to 60 days, and with recurrence intervals of 1 through 500-years.

4.3.6.2. Range of magnitude

Maximum Rainfall Amounts Observed in Twin Cities, Hennepin County and Minnesota		
Rainfall duration	Hennepin County	Minnesota
24 hours	Official: 10.00 inches, MSP July 23-24, 1987 Unofficial: 12.75 inches, Bloomington, July 23-24, 1987	Official: 15.10 inches, Hokah, Aug 18-19, 2007 Unofficial, La Crescent, 17.21 inches, August 18-19, 2007
5-day	13.80" MSP, July 20-24, 1987	17.45 inches, Hokah, August 18-22, 2007
Monthly	17.90 inches, MSP, July 1987	23.86 inches, Hokah, August 2007

4.3.6.3. Spectrum of consequences (damage scale, common impacts and disruptions, response needs)

The most dangerous result of extreme rainfall is flash-flooding, which has numerous consequences, arises from a combination of factors, and is covered in greater depth as its own chapter within this assessment. Other severe hazards are not related to directly flooding. Following is a brief annotated list of common consequences resulting from extreme rainfall:

- Injury, drowning, death: those unable to get to higher ground, and those stuck in vehicles that either failed to navigate or are unaware of high water are at significant risk. Flooded roads, particularly at night, are especially dangerous.
- Infrastructure damage: roads, culverts, drainage basins, bridges, and even dams can succumb to the direct force of heavy flowing water, and also to erosion from the ground below. Sewer and wastewater systems may overflow.
- Stalled, stranded, or damaged vehicles. Many vehicle batteries die in high water, causing vehicles to stall. Parked vehicles in low-lying areas may also be inundated and stranded. Water frequently gets inside the vehicles, damaging the electronics and the interior.
- Structural failure: eroding soils from a heavy rain may undermine the structural integrity of houses and buildings, resulting in complete or partial collapse.
- Water damage. Water enters sub-grade floors through small openings and in extreme events can accumulate to inches or even feet on the lowest levels, as municipal sewer systems exceed capacity and water backs up into residential lines. Electrical equipment becomes susceptible to damage, and interior materials may be compromised and may develop dangerous mold or mildew.
- Crop damage: it is common for major extreme rainfall events to damage agricultural fields, often wiping out an entire season's worth of crops.

- Water quality: extreme rainfall washes high level of compounds into area waterways, which may exceed allowable contaminant thresholds for days or even weeks after a major event.
- Recreational loss: extreme rainfall events target the lowest areas first, meaning that lakes and rivers are susceptible to overflow. No-wake laws impede water sports, and overflowing streams and rivers can produce dangerous conditions for canoeing and other human-powered water activities. Trails and paths near lakes and rivers are often flooded, preventing bicycling, jogging, and walking. Recreational departments will require extra labor hours to return recreational resources to proper working conditions.

4.3.6.4. Potential for cascading effects

The majority of cascading effects associated with extreme rainfall are identical to those associated with flash-flooding and urban flooding.

Extreme rainfall hazards can easily be compounded by other pre-existing hazards, as well as hazards that develop after an event. In many cases, extreme rainfall--especially of shorter durations--occurs with severe supercell thunderstorms, squall lines, and mesoscale convective systems. Almost by definition, these systems are multi-hazard events. Thus, straight-line downburst winds, large hail, tornadoes, and frequent lightning are often associated with the same storms that produce extreme rainfall rates. Power may be out, which complicates efforts to remove water using sump pumps. This was the case in June of 2013, following a major wind event in the Twin Cities. The July 23-24 super storm produced record-setting and basement-inundating rainfall from storms that also produced heavy damage from tornadoes. There were instances during the evening in which tornado warnings and Flash-Flood warnings were in effect for the same area simultaneously. Seeking shelter in a basement posed flood-related risks.

Extreme rainfall also can play a role in tree mortality, and associated damages to public sidewalks, personal property, and electrical systems. On June 21, 2013, a major tree fall event that was also the largest weather-related power outage in state history, resulted not just from the prolonged downburst winds, but also from intense rains that fell both earlier in the day, and during the storm. Though the winds were 50-60 mph with some higher gusts for over 10 minutes in many places, they produced far more damage than would be expected at those speeds. The severity of tree damage likely resulted from the saturated soils, which provided less resistance than normal, allowing trees to become “loose” and eventually topple.

Whether short or prolonged in duration, extreme rainfall is often associated with summerlike air masses. Thus, extreme rainfall may occur before, during, or after an extreme heat event. Similarly, extreme rainfall can occur during drought conditions, as was the case in 1987.

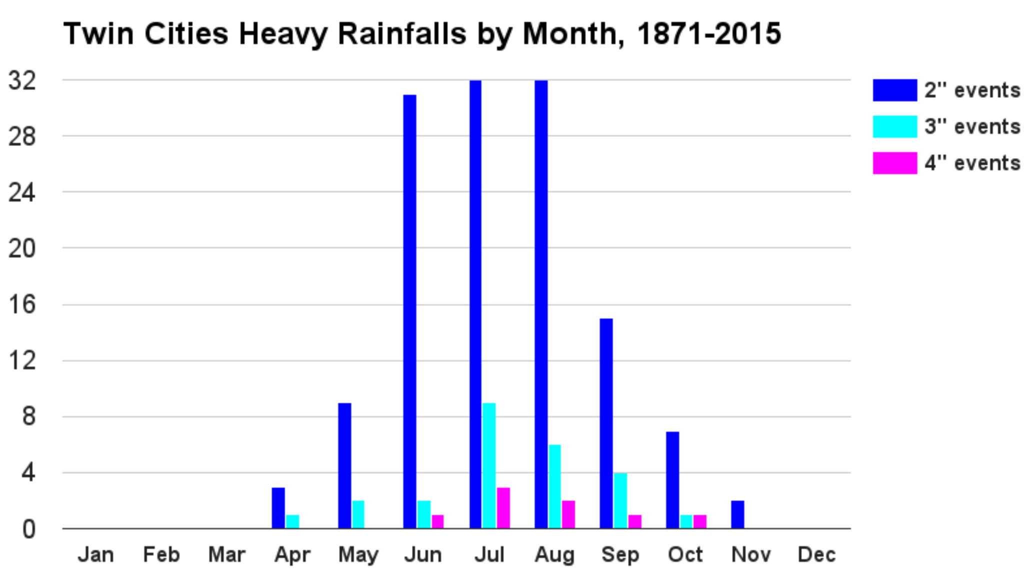
Additional specific cases of high-impact multi-hazard extreme rainfall events will be outlined in the ***Historical (statistical) data/previous occurrence*** section.

4.3.6.5. Geographic scope of hazard

Extreme rainfall rates may cover between 50 and 1500 square miles at a time. After accounting for movement, the total area affected by rainfall in excess of 3 inches may cover thousands of square miles, with hundreds of square miles receiving over six inches of rain. In exceptionally rare cases, 6-inch rainfall totals may cover an area greater than 1,000 square miles--approximately the size of two Twin Cities area counties. The Minnesota State Climatology Office has documented 12 of these “mega” rainfall events in Minnesota since the mid-1800s. These events are always associated with catastrophic damage and often loss of life.

4.3.6.6. Chronologic patterns (seasons, cycles, rhythm)

Extreme rainfall has been observed from April through November, but peak probabilities are generally from June through August, and to a lesser extent, September. The frequency of 3 and 4-inch rainfall peaks during July.



Graphic of 2, 3, and 4-inch daily rainfall totals in Minneapolis since 1871.

Like other convective weather hazards, extreme rainfall goes through more and less active periods. Hennepin County has at times gone many years between major events. 2014, 2002, and 1997, on the other hand, are relatively recent examples of years with multiple extreme events in the county.

4.3.6.7. Historical (statistical) data/previous occurrence

NOAA Atlas 14 is the definitive source for extreme rainfall estimates, and contains the most recent scientific estimates of rainfall amounts for durations from 5 minutes to 60 days, and with recurrence intervals of 1 through 500-years. The following table is for a point selected in central Hennepin County. The top row contains recurrence intervals (or return periods), and the left column is storm durations. The value in bold where they intersect is the likely amount in inches expected for a storm of that duration, at that recurrence interval. The values in parentheses represent the 90% confidence range around the bold value ***Example: For 24-hour rainfall at a 100-year recurrence interval is estimated to be 7.34 inches, and is 90% likely to be between 5.55, and 9.65 inches.***

TABLE 4.3.6A is derived from a statistical technique that utilizes data from multiple stations and is based on observations.

TABLE 4.3.6A Precipitation frequency estimates for a point in central Hennepin County

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]										
Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.355 (0.282-0.452)	0.420 (0.333-0.535)	0.531 (0.420-0.679)	0.628 (0.494-0.804)	0.767 (0.587-1.01)	0.880 (0.657-1.17)	0.997 (0.720-1.35)	1.12 (0.777-1.54)	1.29 (0.862-1.81)	1.43 (0.926-2.01)
10-min	0.519 (0.413-0.662)	0.615 (0.488-0.784)	0.777 (0.615-0.994)	0.919 (0.724-1.18)	1.12 (0.859-1.48)	1.29 (0.962-1.71)	1.46 (1.05-1.97)	1.64 (1.14-2.26)	1.89 (1.26-2.65)	2.09 (1.35-2.95)
15-min	0.633 (0.503-0.807)	0.749 (0.595-0.956)	0.948 (0.751-1.21)	1.12 (0.882-1.44)	1.37 (1.05-1.81)	1.57 (1.17-2.09)	1.78 (1.29-2.41)	2.00 (1.39-2.75)	2.31 (1.54-3.23)	2.54 (1.65-3.59)
30-min	0.895 (0.712-1.14)	1.07 (0.846-1.36)	1.36 (1.07-1.73)	1.61 (1.27-2.06)	1.97 (1.51-2.60)	2.26 (1.69-3.01)	2.56 (1.85-3.46)	2.88 (2.00-3.97)	3.32 (2.22-4.65)	3.67 (2.38-5.17)
60-min	1.16 (0.925-1.48)	1.38 (1.10-1.76)	1.77 (1.40-2.26)	2.12 (1.67-2.71)	2.64 (2.03-3.52)	3.08 (2.31-4.12)	3.56 (2.58-4.83)	4.07 (2.83-5.62)	4.79 (3.20-6.74)	5.37 (3.49-7.58)
2-hr	1.43 (1.15-1.81)	1.70 (1.36-2.14)	2.18 (1.74-2.76)	2.63 (2.08-3.33)	3.32 (2.58-4.39)	3.91 (2.96-5.20)	4.55 (3.33-6.14)	5.25 (3.69-7.21)	6.25 (4.22-8.75)	7.07 (4.63-9.91)
3-hr	1.59 (1.28-2.00)	1.88 (1.51-2.36)	2.42 (1.94-3.04)	2.93 (2.34-3.71)	3.75 (2.94-4.97)	4.46 (3.40-5.92)	5.24 (3.86-7.07)	6.11 (4.32-8.38)	7.37 (5.01-10.3)	8.40 (5.53-11.7)
6-hr	1.87 (1.52-2.33)	2.20 (1.78-2.73)	2.83 (2.29-3.52)	3.44 (2.77-4.31)	4.43 (3.51-5.83)	5.29 (4.08-6.99)	6.26 (4.66-8.39)	7.33 (5.24-10.0)	8.91 (6.11-12.4)	10.2 (6.78-14.1)
12-hr	2.14 (1.75-2.63)	2.52 (2.06-3.11)	3.25 (2.65-4.01)	3.93 (3.19-4.87)	5.00 (3.98-6.49)	5.92 (4.58-7.71)	6.92 (5.18-9.17)	8.04 (5.78-10.8)	9.64 (6.67-13.2)	11.0 (7.34-15.1)
24-hr	2.50 (2.06-3.05)	2.87 (2.37-3.51)	3.59 (2.95-4.40)	4.28 (3.50-5.25)	5.36 (4.32-6.90)	6.31 (4.93-8.15)	7.34 (5.55-9.65)	8.49 (6.16-11.4)	10.2 (7.09-13.8)	11.5 (7.79-15.7)
2-day	2.92 (2.43-3.53)	3.27 (2.72-3.96)	3.96 (3.28-4.80)	4.63 (3.82-5.63)	5.72 (4.65-7.29)	6.67 (5.27-8.55)	7.74 (5.91-10.1)	8.93 (6.54-11.9)	10.7 (7.51-14.4)	12.1 (8.25-16.4)
3-day	3.17 (2.65-3.81)	3.54 (2.96-4.26)	4.26 (3.55-5.13)	4.95 (4.11-5.99)	6.06 (4.94-7.67)	7.03 (5.58-8.95)	8.11 (6.21-10.5)	9.30 (6.84-12.3)	11.0 (7.82-14.9)	12.5 (8.55-16.8)
4-day	3.37 (2.83-4.04)	3.78 (3.17-4.53)	4.54 (3.80-5.45)	5.27 (4.38-6.34)	6.40 (5.23-8.05)	7.39 (5.87-9.35)	8.47 (6.51-10.9)	9.66 (7.13-12.7)	11.4 (8.08-15.2)	12.8 (8.80-17.2)
7-day	3.88 (3.28-4.61)	4.39 (3.71-5.22)	5.30 (4.46-6.31)	6.12 (5.12-7.31)	7.34 (6.01-9.09)	8.37 (6.67-10.4)	9.46 (7.30-12.0)	10.6 (7.88-13.8)	12.3 (8.78-16.3)	13.7 (9.45-18.2)
10-day	4.38 (3.72-5.17)	4.96 (4.21-5.86)	5.96 (5.04-7.06)	6.84 (5.75-8.13)	8.12 (6.65-9.97)	9.17 (7.33-11.4)	10.3 (7.94-13.0)	11.4 (8.50-14.7)	13.1 (9.34-17.2)	14.4 (9.98-19.1)
20-day	5.96 (5.11-6.97)	6.66 (5.71-7.80)	7.84 (6.69-9.20)	8.83 (7.50-10.4)	10.2 (8.42-12.3)	11.3 (9.11-13.8)	12.4 (9.68-15.5)	13.6 (10.2-17.3)	15.1 (10.9-19.7)	16.3 (11.4-21.5)
30-day	7.35 (6.33-8.54)	8.19 (7.05-9.52)	9.54 (8.19-11.1)	10.7 (9.10-12.5)	12.2 (10.1-14.6)	13.3 (10.8-16.1)	14.5 (11.3-17.9)	15.6 (11.7-19.7)	17.1 (12.4-22.1)	18.3 (12.9-24.0)
45-day	9.15 (7.93-10.6)	10.2 (8.84-11.8)	11.9 (10.3-13.8)	13.2 (11.3-15.4)	15.0 (12.4-17.7)	16.3 (13.2-19.5)	17.5 (13.7-21.4)	18.7 (14.1-23.4)	20.2 (14.6-25.8)	21.2 (15.0-27.7)
60-day	10.7 (9.31-12.3)	12.0 (10.4-13.8)	14.0 (12.1-16.2)	15.6 (13.4-18.1)	17.6 (14.6-20.7)	19.0 (15.5-22.7)	20.4 (16.0-24.7)	21.6 (16.3-26.9)	23.1 (16.8-29.4)	24.1 (17.1-31.3)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

The 100-year recurrence value for 24-hour rainfall is the most frequently cited value, and indeed, many structure are designed for such an event. It is, however, important to note that shorter durations of excessive rainfall can also overwhelm systems, and many have therefore been designed for 1, 3, or 6-hour thresholds. Structural, civil, and hydrological engineers can provide further information on exceedance thresholds used for particular infrastructure elements. Additionally, heavy rainfall over longer durations can overwhelm systems, even when exceptional hourly rainfall rates are lacking.

Extreme rainfall, therefore, should be anticipated on a variety of timescales, and not just measured by daily or 24-hour rainfall only. Radar estimates and automated rain gauges help forecasters understand rainfall quantities for shorter and longer durations, and noteworthy rainfall events of many duration-magnitude combinations have affected Hennepin County.

July 23-24, 1987 Super Storm

The heaviest rainfall ever officially recorded at a Twin Cities weather station fell between about 18:00 CDT on 23 July and about 02:00 CDT on 24 July 1987. During this eight-hour interval, observers at the Twin Cities International airport station measured an even ten inches of rain (9.15 inches of which fell in a five hour period). In addition to the heavy rainfall, the 23-24 July storm spawned an F3 tornado near Goose Lake in Hennepin County, and produced extensive damage in Maple Grove and Brooklyn Park. Damage in other areas was extensive, largely the result of flooded homes and businesses, ruptured storm sewers, and washed out or inundated streets and highways. Two flood related deaths were reported and property damage was estimated to be in excess of $30 million (1987 dollars).

The 23-24 July storms occurred along an outflow boundary that had separated extremely warm, moist air to the south and east and much cooler, drier air immediately to the north and west. The interaction of these air masses produced intense thunderstorms with extremely heavy rainfall over the southwestern portion of the Twin Cities on 20-21 July 1987, two days prior to the 23-24 July outbreak. Rainfall amounts during this event included 3.83 inches at the Twin Cities airport station, 9.75 inches near Shakopee and 7.83 inches at the neighboring community of Chaska.

The 23-24 and 20-21 July storms, together with the rainfall produced by thunderstorms earlier and later in the month, brought unprecedented July rainfall to the Twin Cities area. The International airport station recorded 17.91 inches, approximately six times the July normal. An unofficial monthly total of 19.27 inches was recorded in west Bloomington.

Ironically, July 1987's excessive rainfall came in the middle of a prolonged period of subnormal precipitation. Precipitation had been below normal for every month from October 1986 through June 1987 and, following about six weeks of wet weather in July-August 1987, the drought returned. Extreme dryness prevailed during much of the ensuing year with a near record dry June and record warmth during the summer of 1988.

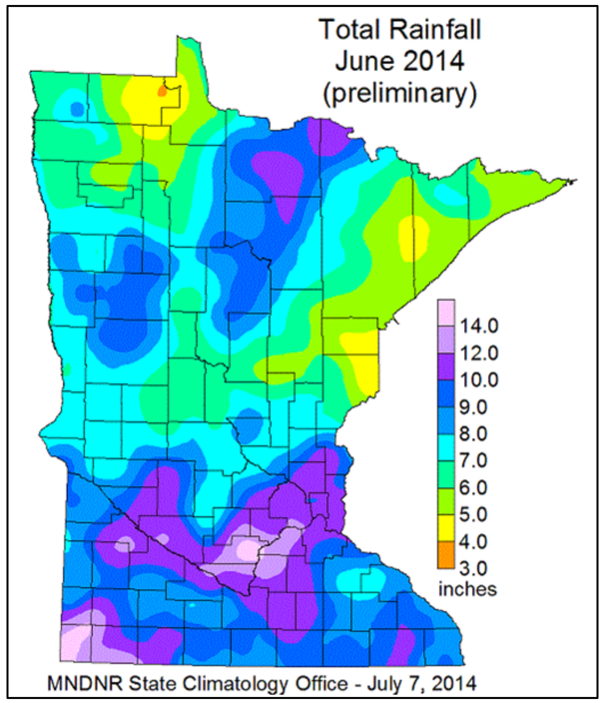
July 1, 1997 Derecho and Flood

An intense mesoscale system containing supercells and a fast-moving squall line tore through the central and northern Twin Cities area during the evening, producing extensive wind damage and catastrophic flooding. Numerous tornadoes rated up to F3, were reported from the Willmar area, through Wright and Sherburne Counties. Non-tornadic winds in excess of 100 mph knocked out power, severely damaged structures, and snapped and uprooted trees in Wright, Anoka, Sherburne and northern Hennepin counties.

As the storm complex moved into the central portions of the Twin Cities, it produced some of the heaviest one-hour rainfall ever measured in Minnesota. 3-4 inches fell within one hour over the central and eastern parts of Hennepin County, as well as adjacent portions of Ramsey and Anoka counties. I-35 and I-94 were closed south of downtown Minneapolis, and standing water in excess of 10 feet in some areas prompted boat rescues in south Minneapolis and Richfield. Edison High School in northeast Minneapolis sustained major flood damage, and hundreds of homes and residential complexes were severely damaged by inundation.

Late May through June, 2014 - repeated/persistent heavy rainfall events

A persistently wet pattern punctuated by numerous heavy rainfall events during June 2014 led to significant flooding and estimates of approximately $12 million in damage throughout Hennepin County. The greatest impacts tended to be focused near water bodies and low-lying areas. Numerous stations in Minnesota reported record monthly rainfall for June.



May 31- June 2: 2-4 inches of rainfall was common over the county, with 4.3” reported at Flying Cloud. This was part of a nearly statewide heavy rainfall event. Lake Minnetonka rose to its highest levels in 109 years following this event.

June 6-8: A scattered rainfall event, with up to 2 inches in western Hennepin County, and an isolated 3-inch report near Independence.

June 14-16: 2-3 inches throughout the county. Levels began rising rapidly along many waterways.
June 18: Isolated reports of up to 1 inch in association with a major event concentrated over southern MN, and in advance of the more significant event on the following day

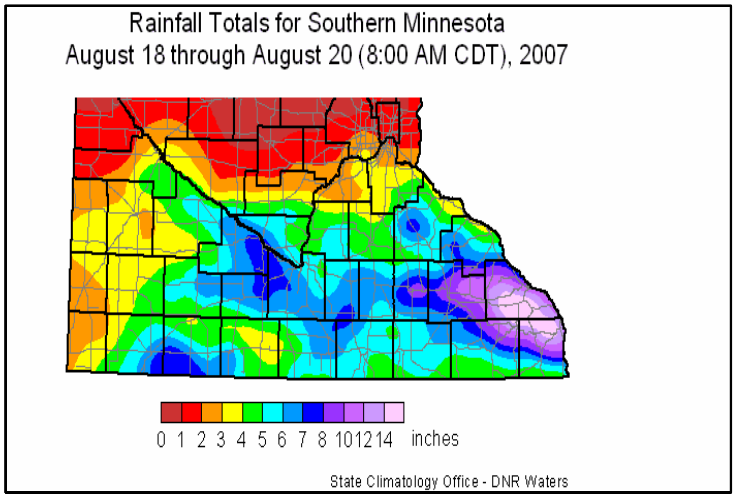
June 19: Major, long-duration intense rainfall event, with waves of heavy precipitation throughout the day. Flooding became common and widespread. 3-5 inches were common throughout the county, with 4.13 reported at MSP—the heaviest daily total since October 2005. 5.47” was reported by CoCoRaHS in Eden Prairie. Seven-day rainfall amounts of 4-8 inches were common across the county, with even more to the south and west.

Municipalities, school districts, and other public interests within Hennepin County reported losses and expenses in excess of $12 million USD (2014). The following list is not exhaustive, but rather representative of the scale and impact of damage from the excessive rainfall.

- Bloomington, **$265-270k**: parkland damage; destruction of warming house
- Eden Prairie, **$360-370k**: pipe ruptures damage to Duck Lake Trail, Eden Prairie Road, recreational trails, sewers, and banks of Riley Creek
- Golden Valley, **$90-95k**: unspecified damages to roads, sewers, culverts
- Greenfield, **$20-25k**: roads, sewers
- Hennepin County Sheriff's Office, **$26k**: water patrol docks and one boat damaged
- Hopkins School District, **$5k**: washouts at High School, West Jr. High, Gatewood Elementary, and Eisenhower
- Minneapolis Park Board, **$6.8M**: Mudslide behind Fairview-Riverside affecting 100' x 250' slope and exposing facility oxygen tanks and require extensive re-engineering and restoration
- Minnehaha Creek Watershed District, **$180k:** Lake Minnetonka reached record high water mark of 931.11 feet, and Minnehaha creek exceeded 100-year flow at Hiawatha (with 893 cu ft.). The entire creek watershed was severely impacted, as were many of the MCWD's capital projects
- Minnetonka, **$55k**: unspecified damages to municipal property
- Minnetonka Independent School District, **$NA**: Destruction/failure of retaining wall at high school
- Mound, **$1M**: unspecified damages to streets, culverts, sewers, parks and infrastructure
- Orono, **$150k**: severe damage to Starkey Road and Balder Park Road
- Park Nicollet Methodist Hospital, **$3.6M**: Drainage system destroyed; sunken grade creating sinkhole risk; low-lying electrical circuitry inundated and damaged, pumping, sandbagging and dewatering required; barriers construction
- Richfield, **$70-75k**: Power failure at sanitary lift station, damage to pumps, trails and paths inundated, littered with debris, and damaged
- St. Louis Park, **$50-55k**: severe damage on Louisiana Ave
- Wayzata, **$70-75k:** city marina flooded and damaged; culverts damaged, requiring emergency repairs.

August 18-20, 2007 - worst rainfall event on record in MN

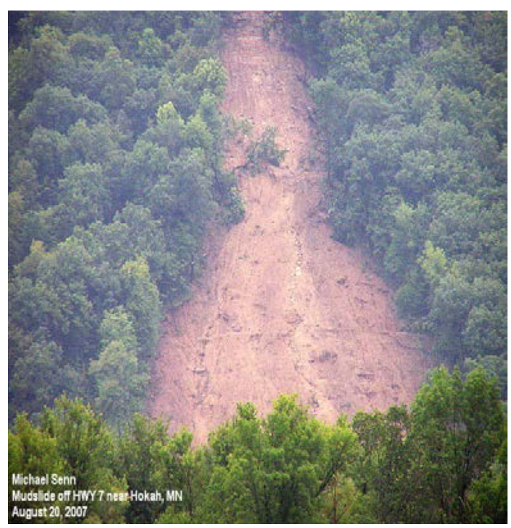
Perhaps the most extraordinary precipitation event in Minnesota's modern history shattered Minnesota's 24-hour rainfall record. The 15.10" total recorded at 8:00 AM on Sunday, August 19, 2007 near Hokah in Houston County is the largest 24-hour rainfall total ever measured at an official National Weather Service observing station in Minnesota, breaking the old record of 10.84 inches by an astonishing 39%.



Rainfall totals for entire 3-day rainfall event in southern Minnesota in august of 2007. In most areas, 80-90% of the totals came within the first 24 hours of the event.

The storm also obliterated the state's "unofficial" rainfall record, when a non-National Weather Service rainfall observer near La Crescent (Houston County) reported 17.21 inches for the 24-hour period ending 7:00 AM, Sunday, August 19. This is the largest 24-hour value in the Minnesota State Climatology Office database, and broke the previous statewide *non-NWS observer* record 12.75" by a margin of 35%. Both new records far exceeded expected totals, even for record-breaking events, and are so large, a true return period estimation is virtually impossible.

The rainfall was caused by a series of strong thunderstorms moving along a stalled frontal boundary for an unusually long time. The most intense precipitation rates occurred during the afternoon and evening hours of Saturday, August 18, and the early morning hours of Sunday, August 19. Over the course of the event, all or portions of 28 counties received at least four inches of rain. Six-inch totals were common across the region, and portions of southeastern Minnesota reported three-day totals ranging from 8 to 20 inches. The heaviest rainfall reports came from Winona, Fillmore, and Houston counties, where 36-hour totals exceeded 14 inches. The largest multi-day rainfall total reported (through Monday, August 20) was 20.85 inches observed near the town of Houston in northern Houston County.



Damaging mudslide near Hokah. Courtesy of NWS- La Crosse

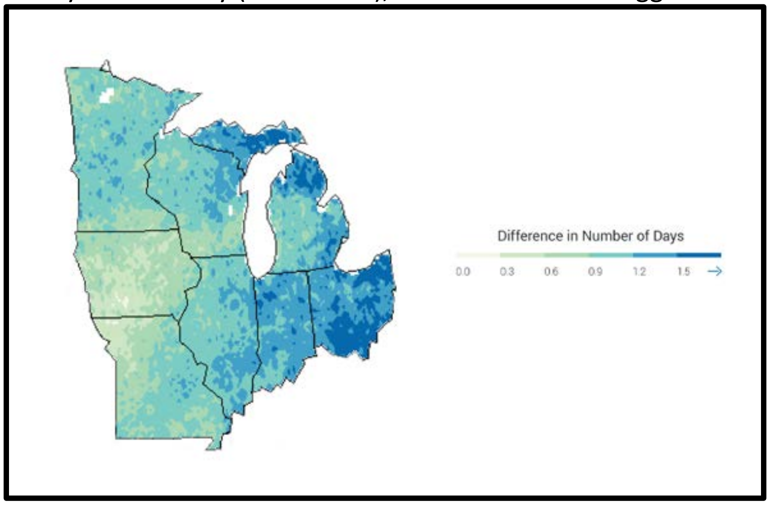
The deluge produced flooding tied to seven fatalities. Major flood damage occurred in many southeastern Minnesota communities. Hundreds of homes and businesses were impacted.

Reports of stream flooding, urban flooding, mudslides, and road closures were numerous throughout southern Minnesota.

The combination of huge rainfall totals and a very large geographic extent, make this an extraordinary episode. The area receiving six or more inches during a 24-hour period in the midst of this torrent encompassed thousands of square miles- the largest such area known to the Minnesota State Climatology Office.

4.3.6.8. Future trends/likelihood of occurrence

The 2014 National Climate Assessment indicates that observed trend, of increasing frequency *and* magnitude of extreme rainfall, will continue. By mid-century (2041-2070), the latest science suggests that rainfall events that would ranking in the top 2% for the period 1981-2010, will become more common. Most of Minnesota can expect, on average, an additional day per year with these events, which amounts to an approximate doubling in frequency.



Additional days per year with upper 2% rainfall events by mid-century (2041-2071). Source, *2014 National Climate Assessment, Midwest Chapter*.

4.3.6.9. Indications and Forecasting

The Chanhassen Office of the National Weather Service is the local authority for extreme rainfall monitoring and forecasting, and uses flash flood guidance, based on soil moisture and land cover conditions, to evaluate whether expected and/or ongoing heavy rainfall poses a significant flooding risk. Additionally, NOAA's Weather Prediction Center (WPC) has a legacy of advanced hydro-meteorological monitoring and prediction, and offers Excessive Rainfall Outlooks and Mesoscale Precipitation Discussions that are comparable to the severe weather products offered by the Storm Prediction Center. Unlike the Storm Prediction Center, however, the WPC does not issue Watches of any sort.

Forecasters monitor and analyze numerical weather models and other predictive tools to ascertain potential extreme rainfall and associated flash flooding threats. The following sequence of products may then be used in an idealized situation, though it should be noted that extreme rainfall threats may appear of disappear at any step in this timeline:

4+ days out: Chanhassen NWS Office highlights threat for heavy or extreme rainfall and flash flooding potential in Hazardous Weather Outlook products.

1-3 days out: WPC issues Excessive Rainfall Outlook, indicating Marginal, Slight, Moderate, or High Risk of excessive rainfall, according to the following probabilities:

Risk Category	Probability of Rainfall Exceeding Flash Flood Guidance at a Point
Marginal (MRGL)	2-5%
Slight (SLGT)	5-10%
Moderate (MDT)	10-15%
High (HIGH)	>15%

Current/valid Excessive Rainfall Outlooks can be found at: http://www.wpc.ncep.noaa.gov /qpf/ excess _rain.shtml

Within 48 hours: Chanhassen NWS Office issues Flash Flood Watch, based on combination of expected precipitation and local Flash Flood Guidance values.

→ ***Important:*** *In early spring 2018, the NWS will no longer use Flash Flood Watches, and will instead consolidate them into generic Flood Watches, as part of its Hazard Simplification process: https://www.weather.gov/news/170307-hazard-simplification*

Within 1-6 hours: WPC issues Mesoscale Precipitation Discussion to highlight emerging flooding potential from expected, developing, or ongoing thunderstorm and rainfall activity. These discussion are only used for large areas of concern (generally the size of 25 or more Minnesota counties) and do not pertain to highly localized extreme events.

Each discussion includes an annotated graphic indicating the area of concern, and a brief text discussion focused on the mesoscale features supporting the anticipated heavy rainfall. The potential for flash flooding within the area of concern will be highlighted by one of three headlines:

FLASH FLOODING LIKELY High confidence exists that environmental conditions are favorable, or will become favorable, for heavy rainfall that will result in flash flooding.

FLASH FLOODING POSSIBLE Environmental conditions are favorable, or will become favorable, for heavy rainfall, but there are questions about how the event will evolve and/or whether flash flooding will occur.

FLASH FLOODING UNLIKELY High confidence exists that environmental conditions are unfavorable, or will become unfavorable, for heavy rainfall that will result in flash flooding.

Once event has begun: Chanhassen NWS Office issues Flash Flood Warning, based on combination of precipitation received, further precipitation expected, soil conditions, and stream levels and flow. A Flash Flood Warning is issued when flash flooding is occurring or is imminent. These warnings differ from Severe Thunderstorm and Tornado warnings, in that they are not issued in advance of the parent thunderstorm(s), but instead after the storm has begun, ideally in advance of the flash-flooding itself. The behavior of approaching storms is erratic enough that pre-storm lead time for flash-flood warnings would lead to high false alarm rates.

Flash Flood Warnings are issued as polygons that attempt to match the spatial extent of the true threat (as opposed to covering entire counties). Like Severe Thunderstorm warnings, they may cover slivers of counties, or multi-county swaths. The warning period depends on the duration of the event itself, but Flash Flood Warnings may continue for several hours after the precipitation has subsided.

4.3.6.10. Detection & Warning

The Chanhassen NWS Office and North Central River Forecast Center (adjoining the Chanhassen office) monitor local flood conditions using a combination of manual and remotely-sensed information. Key warning detection and decision sources include but are not limited to:

- Radar-estimated precipitation, which can be used in conjunction with flash flood guidance values to determine flood potential
- Automated, real-time stream gaging, which indicates the level and flow of critical streams
- Real-time, manual or automated rainfall reports
- Radar and local meteorological trends, indicating potential for storms to continue and/or redevelop in or near affected areas
- Reports from spotters, emergency managers, first responders, the media, and the public
- Images or videos shared via social media or other means

The Chanhassen NWS Office will issue a Flash Flood Warning if the forecasters determine that information from the above and other detection sources indicate that flash flooding is occurring or is imminent in a given area.

4.3.6.11. Critical values and thresholds

Unlike other weather hazards, Watch and Warning thresholds for flash floods vary with the pre-existing meteorological conditions. Conditions with saturated soils and high or overtopped streams require substantially less precipitation to generate flash-flooding than conditions with low soil moisture and low stream levels. Although some anticipated precipitation amounts may suggest to forecasters that flash flooding is possible, irrespective of soil conditions, the Watch and Warning thresholds are generally determined on a case-by-case basis, by considering the Flash Flood Guidance for the area(s) of concern.

Flash Flood Guidance (FFG) values estimate the average amount of rainfall (in inches) for given a duration required to produce flash flooding in the indicated county or area. These values are based on a combination on current soil moisture conditions and land cover considerations, and therefore change in response to the local hydro-climatic situation. Throughout much of Hennepin County, and especially in urban areas, less rainfall is required to produce flash flooding than in many neighboring areas, because of the county's high concentration of impervious surfaces.

Current flash-flood guidance for 1, 3, and 6-hour rainfall can be found at:

- http://www.weather.gov/images/ncrfc/data/ffg/images/ffg_1hr_latest.gif
- http://www.weather.gov/images/ncrfc/data/ffg/images/ffg_3hr_latest.gif
- http://www.weather.gov/images/ncrfc/data/ffg/images/ffg_6hr_latest.gif

4.3.6.12. Prevention

To improve water management and protect the sewage system from damage, cities can revamp their underground pipe and drainage systems by separating rainwater from the sewage system. The separation enables the wastewater treatment plant to function properly, without it being overburdened by large quantities of storm water.

Other more obvious methods are to keep sewer systems clean of clog up with waste, debris, sediment, tree roots and leaves.

4.3.6.13. Mitigation

Areas that have been identified as flood prone areas can be turned into parks, or playgrounds, buildings and bridges can be lifted, floodwalls and levees, drainage systems, permeable pavement, soil amendments, and reducing impermeable surfaces. Reducing impervious surfaces could include the addition of green roofs, rain gardens, grass paver parking lots, or infiltration trenches.

Other mitigation strategies include developing a floodplain management plan, form partnerships to support floodplain management, limit or restrict development in floodplain areas, adopt and enforce building codes and development standards, improve storm water management planning, adopt policies to reduce storm water runoff, and improve the flood risk assessment.

4.6.3.14. Response

One of the most important things to be done during the initial response is to make sure that people are safe. If their homes have been damages and are unlivable, finding a place for them to stay is among one of the top priorities. Next is the access to places if roads are washed out or still underwater. One complicated factor with flood disasters, is sometimes you do not know how bad the damage is until the water recedes, which can take time and slow the response. Another important part of response is to make sure water supply is available as quick as possible if there has been any contamination. The role of Hennepin County Emergency Management is to coordinate resources that our municipalities may need to accomplish all response needs.

4.6.3.15. Recovery

As mentioned in river flooding, recovery from floods can take weeks, to months, to years. Extreme rainfall/flooding, is unlike quick onset disasters (e.g. tornadoes) where you can see the damage immediately, sometimes with excessive rainfall/flooding you have to wait for the flood waters to recede to find out what damage there is to recover from. A lot of the time, the longer the water level stays too high, the more consequences are introduced that you have to then recover from.

4.6.3.16. References

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4.3.7.	Hazard Assessment: HEAT, EXTREME

4.3.7.1. Definition

Conditions of extreme heat are defined as summertime temperatures that are substantially hotter and/or more humid than average for a location at that time of year. Humid or muggy conditions, which add to the discomfort of high temperatures, occur when an area of high atmospheric pressure traps hazy, damp air near the ground. Extremely dry and hot conditions can provoke dust storms and low visibility. Typically when extreme heat conditions last for two days or longer, they are called heat waves.

4.3.7.2. Range of Magnitude

The magnitude of extreme heat can vary greatly. You can have extreme heat events where you have shorter periods (3-5 days) with much higher than normal temperatures, or you can have longer periods (2-3 weeks) with temperatures only a 5-10 degrees higher than normal temperatures.

- Hottest Heat Wave on record MN: July 18, 2011
- Longest Heat Wave on record MN: August 4-8, 2001
- Most Recent Heat Wave for Hennepin County: August 25th, 2013
- Deadliest MN Heat Wave: August 4-8, 2001; 5 fatalities

4.3.7.3. Spectrum of Consequences

Extreme heat can be just as deadly as other natural hazards by pushing the human body beyond its limits. Under normal conditions, the body's internal thermostat produces perspiration that evaporates and cools the body. However, in extreme heat and high humidity, evaporation is slowed and the body must work extra hard to maintain a normal temperature. Most heat disorders occur because the victim has been overexposed to heat or has over exercised for his or her age and physical condition. Effects can be seen through just a few people or by many depending on extent the temperatures rise above normal, or other hazards occurring simultaneously. People most at risk include elderly and very young persons, chronically ill patients, socially isolated people, urban residents, and people without access to air conditioning.

There are different conditions, or disorders, related to extreme heat illnesses: heat stress, heat exhaustion, heat stroke, and hyperthermia. Heat stress is the perceived discomfort and physiological strain associated with exposure to hotter than normal environment, especially during physical activity. Heat exhaustion is a mild-to-moderate illness due to water or salt depletion resulting from exposure to extreme heat conditions or strenuous physical activity. Heat stroke is a severe illness resulting from exposure to environmental heat, or strenuous physical exercise during extreme heat conditions. Heat stroke is characterized by a human body core temperature greater than 104^{o}F along with central nervous system abnormalities such are delirium, convulsions, or coma. Heatstroke can have a fast onset and poor survival rate.

4.3.7.4. Potential for Cascading Effects

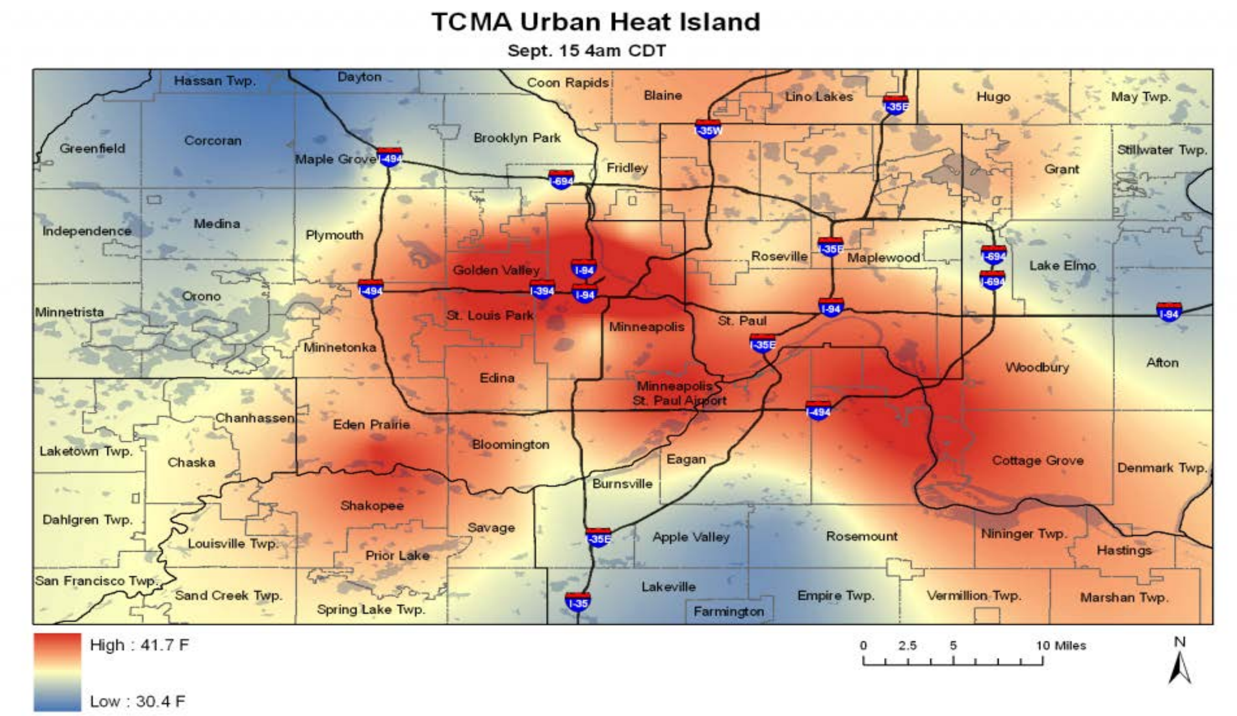
One complicating factor when discussing impacts of extreme heat, is extreme heat doesn't necessarily immediately impact people when it sets in, instead it is when the periods of extreme heat last for days and weeks that it takes its toll on people. An additional complicating factor is when extreme heat conditions are paired with another hazard. For example, if severe thunderstorms affect an area and knock out power right before extreme heat sets in, you now have additional people exposed to extreme heat without working air conditioners. Extended durations of extreme heat can also exacerbate drought conditions and can also lead to excessive power consumption needs causing the potential for brown- and black-outs, which would only make the exposure conditions worse.

Extended periods of extreme heat also contribute to wildfire hazard through a process wherein natural materials, particularly sand and bare soil absorb solar radiation, holding the heat very near the surface, resulting in extremely high surface temperatures. The hot surface heats the overlying air, which rises, carrying the heat upward. The extremely hot surfaces generate strong updrafts, essentially creating local winds that dry surrounding vegetation, increase fuel temperatures and intensify and spread wildfires. The dry vegetation, high fuel temperatures, and high winds increase the static electricity, increasing the potential for spontaneous combustion, particularly during prolonged periods of drought. Extreme heat temperatures can also force the closure of airports due to the lack of sufficient air density for take-offs and landings.

4.3.7.5. Geographic Scope of Hazard

If and when this hazard happens, it can be as small as a local hazard, or countywide with areas of highest concern in the largest metropolitan areas because of the Urban Heat Island. Urban heat islands are large metropolitan urban areas that are warmer in temperature than surrounding rural areas because of pavement, blacktop, and buildings. The University of Minnesota conducted a study showing the Twin Cities metro area temperature differences in 2011. **Graphic 4.3.7A** illustrates measured temperature differences of up to 10 degrees just within Hennepin County.

Graphic 4.3.7A



4.3.7.6. Chronologic Patterns

While the definition of extreme heat indicates an extended period of time where temperatures are above average high temperature, you typically see extreme heat as an issue during the summer months of May through September in Hennepin County.

4.3.7.7. Historical Occurrence

There have been several past instances of extreme heat in Hennepin County. The earliest records of extreme heat include the Dust Bowl of the 1930's. The Dust Bowl years of 1930-36 brought some of the hottest summers on record to the United States, especially across the Plains, Upper Midwest and Great Lake States. For the Upper Mississippi River Valley, the first few weeks of July 1936 provided the hottest temperatures of that period, including many all-time record highs.

Two consecutive heat waves occurred in 1999. The first was on July 23-25, 1999 when a massive upper ridge over the central U.S. enabled heat to build into Minnesota. Heat indices ranged from 95-110 on the 23rd, 90-105 on the 24th, and climaxed at 95-116 on the 25th. One death resulted from the heat wave after a man fell asleep inside a closed vehicle on the 25th. The second heat wave of 1999 occur less than a week later for central and south central Minnesota. This heat wave lasted from July 29th, 1999 through July 30th, 1999. This heat wave was stronger with heat indices climbing to the 95-114 range with lows in the 70s and dew points in the middle 60s to 70s which produced heat indices 70-85 even in the morning hours.

In 2001, there were another two heat waves, one that was from July 30 through August 1st, and a second from August 4th through August 8th. The July 30th-August 1st heat wave is commonly known for the heat wave where Minnesota Vikings football player Corey Stringer collapsed on the football field around midday on July 31 in Mankato and was taken to the hospital. Mr. Stringer died early on August 1st, 2001. The second heat wave of 2001 came just three days later and persisted for five days. This heat wave produced five fatalities all within Hennepin County. Hot weather and tropical-like humidity pervaded the region, as virtually all stations registered highs in the 90s all five days. Minneapolis-St. Paul (MSP) reached 98 or 99 three straight days (August 5-7) when highs were 98, 99 and 98 respectively; the highs at MSP on August 6 and August 7 set records. A few noteworthy heat indexes, including the highest known value around Minnesota for each day, are:

- August 4 - 110 at Morris (Stevens County), 107 at Redwood Falls (Redwood County), and 102 at MSP.
- August 5 - 114 at Alexandria (Douglas County) and Morris (Stevens County), 110 at Maple Lake (Wright County) and Montevideo (Chippewa County), and 107 at Mankato (Blue Earth County) and at MSP.
- August 6 - 118 at Rush City (Chisago County), 114 at Redwood Falls (Redwood County), 110 at Faribault (Rice County), and 109 at MSP.
- August 7 - 117 at Morris (Stevens County), 116 at Redwood Falls (Redwood County), 109 at MSP, and 107 at Staples (Todd County).
- August 8 - 102 at Little Falls (Morrison County) and Staples (Todd County), 100 at Appleton (Swift County), and 95 at MSP.

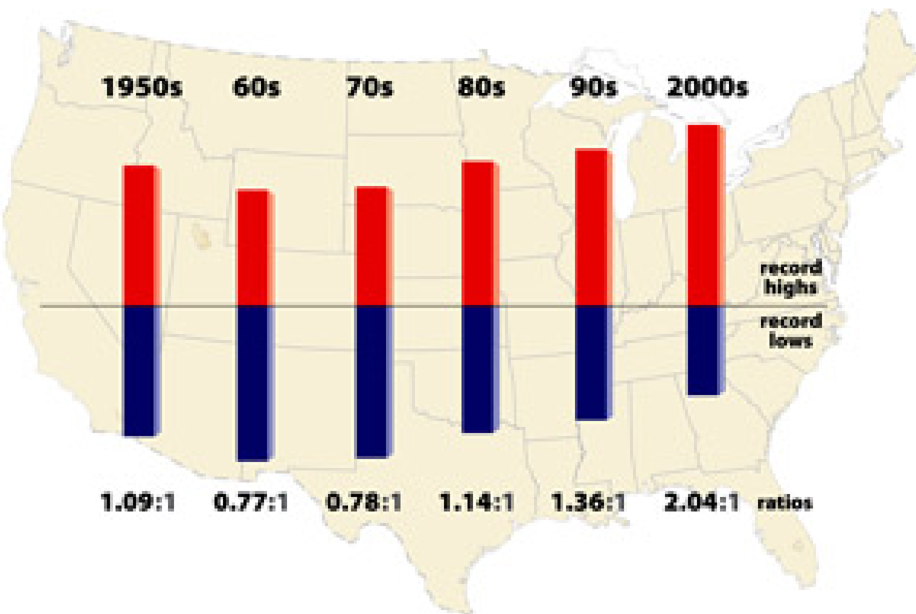
Another heat wave occurred in 2005. High temperatures at Minneapolis-St. Paul International Airport remained at or above 90 degrees for 9 consecutive days between July 9th and 17th. This extended period of hot weather set a record for the 3rd longest streak of at or above 90 degree highs since 1891 in the Twin Cities. On July 12th, a laborer putting up a fence in Arden Hills in Ramsey County suffered severe heatstroke. He collapsed at the work site and was rushed to a local hospital. His body temperature reached 108.8 degrees, but miraculously he survived after receiving intensive medical attention. He awoke from a medically-induced sedation 24 hours after falling ill and made a full recovery.

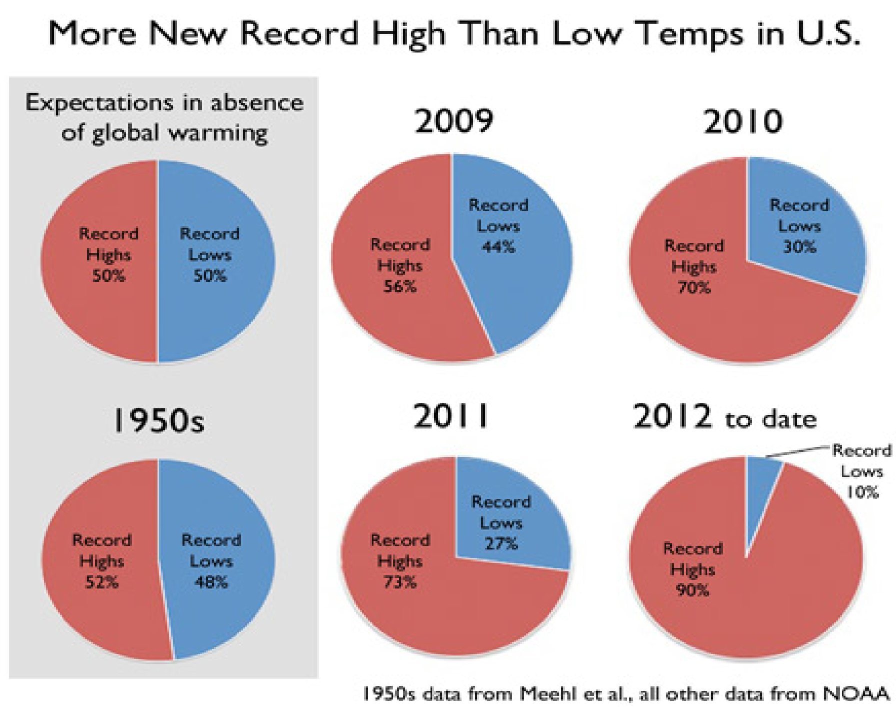
Two heat waves occurred in 2011, one in June and one in July. The June heat wave occurred on June 7th, where it broke the all-time true temperature record for the day at 103°F. This was the warmest day in the Twin Cities in almost 23 years, when July 31, 1988 had a high of 105 degrees. The second heat wave of 2011 occur in July as a large ridge of high pressure expanded across the Upper Midwest and allowed for a stagnant pattern, and eventually oppressive heat and humidity to develop. The heat wave broke records for temperature and dew point, and even heat indices across the region. Maximum heat index values of 115 to 125 were common. A record high minimum temperature was set on July 18th, when a low temperature of 80 degrees was recorded at Minneapolis - St. Paul International Airport. The previous record was 78 degrees which was set in 1986. A record high minimum temperature was also set on July 20th, when a low temperature of 80 degrees was recorded. The previous record was 76 degrees which was set in 1901, 1935 and 1940. A total of 44 fans were treated at Target Field (32 treated in their first aid facilities and more than a dozen treated in their seats). The heatwave led to record power demand. Xcel Energy set a new record with the highest one-day peak demand ever of a little more than 9,500 megawatts on Monday, July 18th. The heat affected turkeys in southwest Minnesota, where 50,000 turkeys died due to heat related causes near Redwood Falls. In addition to the turkeys that died, several news articles had references to heat related deaths to livestock in southern and western Minnesota, but the articles were not specific for counties. The heat and humidity were also blamed for road buckling on I-94 in Minneapolis. Two lanes of northbound I-94 at Lowry Ave, and two lanes of eastbound I-94 at 49th Ave, were closed because of buckling pavement.

The most recent heat wave occurred in 2013 specifically August 25th through August 27th. A large ridge of high pressure built across the central part of the United States during the last week of August. Heat and humidity increased across the Upper Midwest starting the weekend of August 25th, and lasted until the latter part of the week with a string of 90+ afternoon temperatures, combined with dew points in the 70s, caused heat indices to rise above 100 degrees from Sunday, through Tuesday, August 27th. In the Twin Cities metro area, heat indices remained above 80 degrees overnight, and afternoon heat indices continued above 100 degrees through Thursday afternoon, August 29th. The Minnesota State Fair was going on during the time period. 216 people required treatment at medical stations at the fair for heat related illnesses, 10 of whom were transported to local area hospitals. In addition, several record high temperatures were observed, and a dew point temperature of 77 degrees on August 27th at 3:00 PM tied the MSP high dew point temperature record set on August 27, 1990. It also tied the record for highest dew point ever during the State Fair (77 degrees - August 28, 1955 and August 27, 1990). Minneapolis schools canceled all outdoor after-school athletics practices during this period. The August 26th high of 96 degrees in the Twin Cities broke the 94-degree record set in 1948. In Hennepin County, from the 25th through the 29th, there were 28 people who were treated for heat related illnesses, either as walk-ins at emergency rooms, or transported by ambulance to hospitals.

4.3.7.8. Future Trends

Numerous studies have documented that human-induced climate change has increased the frequency and severity of heat waves across the globe.
While natural variability continues to play a key role in extreme weather, climate change has shifted the odds and changed the natural limits, making heat waves more frequent and more intense. In an unchanging climate both new record highs and new record lows are set regularly, even while the total number of new records set each year may decrease as time goes on. Sixty years ago in the continental United States, the number of new record high temperatures recorded around the country each year was roughly equal to the number of new record lows. Over the past decade, however, the number of new record highs recorded each year has been twice the number of new record lows, a signature of a warming climate, and a clear example of its impact on extreme weather.


1950s
60s
70s
80s
90s
2000s
record highs
record lows
1.09:1
0.77:1
0.78:1
1.14:1
1.36:1
2.04:1
ratios


More New Record High Than Low Temps in U.S.
Expectations in absence of global warming
Record Highs 50%
Record Lows 50%
2009
Record Highs 56%
Record Lows 44%
2010
Record Highs 70%
Record Lows 30%
1950s
Record Highs 52%
Record Lows 48%
2011
Record Highs 73%
Record Lows 27%
2012 to date
Record Highs 90%
Record Lows 10%
1950s data from Meehl et al., all other data from NOAA

4.3.7.9. Indications and Forecasting

Heatwaves are most common in summer when high pressure develops across an area. High pressure systems can be slow moving and persist over an area for a prolonged period of time such as days or weeks. Not all high pressure systems bring heat waves. However, high pressure that is combined with high temperatures and high dew points are those that bring the extreme heat events. Typically with high pressure, you have clear skies, which allows strong solar inputs as well. There has been a study done in which showed local evaporation also plays a role in causing high moisture values near the surface.

4.3.7.10. Detection & Warning

The two crucial values for the National Weather Service issuing excessive heat products are described below in the definitions of advisory, watch, and warning criteria.

- Excessive Heat Advisory: Maximum heat index at Minneapolis/St. Paul International Airport is expected to reach 105°F or greater for 1 day, or the maximum heat index is expected to reach 100° or greater and an overnight low temperature no cooler than 75°F for 2 days in a row.

- Excessive Heat Watch: Maximum heat index at MSP Airport is expected to reach 105°F or greater for 1 day, or the maximum heat index is expected to reach 100°F or greater and an overnight low temperature no cooler than 75°F for 2 days in a row. In addition, the Heat Watch/Warning System must recommend a watch.

- Excessive Heat Warning: Maximum heat index at MSP 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.

4.3.7.11. Critical Values and Thresholds

The heat index is what gives us the critical values for indications and warnings. The Heat Index is sometimes referred to as the “apparent temperature”. The Heat Index, given in degrees Fahrenheit, is a measure of how hot it feels when relative humidity is added to the actual air temperature.

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution Extreme Caution Danger Extreme Danger

Another measurement that is used to describe how the human body reacts to extreme heat is the Wet Bulb Globe Temperature (WBGT). This is different from the heat index in that it takes wind and solar radiation in to account along with temperature and humidity (which are the only two factors in heat index. The WBGT parameter has been used by the military for heat safety since the 1950s as it is a better representation for individuals who are active in the heat, since wind and sun factor into how out body cools itself off. Many athletic associations including the sports of running, football, tennis, and soccer have used the WBGT as well. The critical values used by the military can be seen below.

Work/Rest and Water Consumption Table

Applies to average sized, heat-acclimated soldier wearing BDU, hot weather. (See TB MED 507 for further guidance.)

Easy Work	Moderate Work	Hard Work
• Weapon Maintenance • Walking Hard Surface at 2.5 mph, < 30 lb Load • Marksmanship Training • Drill and Ceremony • Manual of Arms	• Walking Loose Sand at 2.5 mph, No Load • Walking Hard Surface at 3.5 mph, < 40 lb Load • Calisthenics • Patrolling • Individual Movement Techniques, i.e., Low Crawl or High Crawl • Defensive Position Construction	• Walking Hard Surface at 3.5 mph, ≥ 40 lb Load • Walking Loose Sand at 2.5 mph with Load • Field Assaults

Heat Category	WBGT Index, F°	Easy Work		Moderate Work		Hard Work	
		Work/Rest (min)	*Water Intake (qt/hr)*	*Work/Rest (min)*	*Water Intake (qt/hr)*	*Work/Rest (min)*	*Water Intake (qt/hr)*
1	78° - 81.9°	NL	½	NL	¾	40/20 min	¾
2 (GREEN)	82° - 84.9°	NL	½	50/10 min	¾	30/30 min	1
3 (YELLOW)	85° - 87.9°	NL	¾	40/20 min	¾	30/30 min	1
4 (RED)	88° - 89.9°	NL	¾	30/30 min	¾	20/40 min	1
5 (BLACK)	> 90°	50/10 min	1	20/40 min	1	10/50 min	1

- The work/rest times and fluid replacement volumes will sustain performance and hydration for at least 4 hrs of work in the specified heat category. Fluid needs can vary based on individual differences (± ¼ qt/hr) and exposure to full sun or full shade (± ¼ qt/hr).
- **NL** = no limit to work time per hr.
- **Rest** = minimal physical activity (sitting or standing) accomplished in shade if possible.
- ***CAUTION: Hourly fluid intake should not exceed 1½ qts.***

  Daily fluid intake should not exceed 12 qts.
- If wearing body armor, add **5°F** to WBGT index in humid climates.
- If doing Easy Work and wearing NBC (MOPP 4) clothing, add **10°F** to WBGT index.
- If doing Moderate or Hard Work and wearing NBC (MOPP 4) clothing, add **20°F** to WBGT index.

For additional copies, contact: U.S. Army Center for Health Promotion and Preventive Medicine Health Information Operations Division at (800) 222-9698 or CHPPM - Health Information Operations@apg.amedd.army.mil.
For electronic versions, see http://chppm-www.apgea.army.mil/heat. Local reproduction is authorized.
June 2004

CP-033-0404

4.3.7.12. Mitigation

There are many different ways to mitigate for extreme heat events. Mitigating from the health effects of extreme heat can be having air conditioning, cities opening cooling centers, or adjusting work ours for those individuals who work primarily outside. There are some energy efficiency measures in houses and small commercial buildings can help to keep the indoor environment within comfortable temperature conditions without use of air conditioning during extreme heat events such as: roof deck insulation, wall insulation, high performance windows, and building orientation.

Mitigation strategies that require coordination and construction include shading of buildings, asphalt and other dark surfaces with trees can reduce the urban heat island effect. Solar panels placed on canopies over parking lots and other paved surfaces can also shade and reduce the urban heat island effect. Direct shading of buildings also reduces heat in buildings in the event of power outages in an extreme heat event. However, tree planting requires adequate space, water, and maintenance, and the correct selection of trees. Another mitigation strategy is the management and restoration of parks in urban areas increases vegetated areas, which can help reduce heat island effects. Increasing recreational and riparian spaces in urbanized areas has many additional benefits including health benefits from air and water quality improvements. Additionally, there are pavements that have technologies to reduce heat island effects. The pavements reflect more solar energy, enhance water evaporation, are more porous, or have been otherwise modified to remain cooler than conventional pavements.

Education about extreme heat can also be a strategy. **TABLE 4.3.7A** White-Newsome et al (2014) describe educational strategies in their four-city study:

TABLE 4.3.7A Four City Study

City	Recommendations
Detroit	• Revisit framing of heat warnings • Invest in full scale public relations campaign to educate residents on heat and health • Educate grade school students about climate change • Ensure that county summer campaign includes a heat health component • Develop messages that connect climate change to everyday life
New York	• Identify strategies to prevent oversaturation of messaging (e.g., home-based care providers have many health messages to deliver) • Using focus groups, determine how and where to best promote cooling centers to a greater diversity of vulnerable persons • Make health messages that apply to everyone • Consider additional risk factors in messaging, such as obesity and risk aversion
Philadelphia	• Revisit messaging about where to go (e.g., ride public transportation, cooling centers, mall) during heat waves • Educate people to participate in traditional cooling behaviors • Increase messaging to encourage buddy systems or checking on loved ones • Consider use of social media or partnerships with GenPhilly (http://www.genphilly.org) to remind younger generations to check on vulnerable family members
Phoenix	• Create clearinghouse of projects and materials • Develop —check on your neighbor‖ programs or messaging • Work with Salvation Army on trainings for social service providers • Improve collective definitions of heat wave • Partner with academics to better translate study findings

4.3.7.13. Response

There are many things an individual can do to respond to extreme heat events. The following list is from the American Red Cross:

- Listen to a NOAA (National Oceanic and Atmospheric Administration) Weather Radio for critical updates from the National Weather Service (NWS).
- Never leave children or pets alone in enclosed vehicles.

- Stay hydrated by drinking plenty of fluids even if you do not feel thirsty. Avoid drinks with caffeine or alcohol.
- Eat small meals and eat more often.
- Avoid extreme temperature changes.
- Wear loose-fitting, lightweight, light-colored clothing. Avoid dark colors because they absorb the sun's rays.
- Slow down, stay indoors and avoid strenuous exercise during the hottest part of the day.
- Postpone outdoor games and activities.
- Use a buddy system when working in excessive heat.
- Take frequent breaks if you must work outdoors.
- Check on family, friends and neighbors who do not have air conditioning, who spend much of their time alone or who are more likely to be affected by the heat.
- Check on your animals frequently to ensure that they are not suffering from the heat.

As an Emergency Management agency, opening cooling centers to the public, adjust cooling center and homeless shelter hours to account for those at need during non-traditional open hours are all response strategies used. Many time neighborhood networks are also unofficially activated to check on their elderly and vulnerable populations.

The City of Chicago stated that one of the biggest changes after the 1995 Chicago Heat Wave has been technology. Chicago now has implemented a 311 center phone number to reach City Hall. Someone in another state with an elderly mother living alone in Chicago can call the 311 center, and a well-being check will be conducted by the appropriate agency. This allows the city to be more proactive that reactive when it comes to calls about extreme heat illnesses.

4.3.7.14. Recovery

Like many other weather related disasters, recovery from an extreme heat event is not fast. As mentioned, consequences from extreme heat can begin to show after the extreme heat has subsided so checking on vulnerable populations as part of the response, also carries over to the recovery process. It's important to acclimatize to changes in temperatures. So as the body has started to get used to extreme heat, once the temperature drops back down can have effects as well. Giving the human body time to adjust to these shifts is important to remember for workers who may spend most of their day outside.

4.3.7.15. References

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4.3.8.	Hazard Assessment: DROUGHT

4.3.8.1. Definition

A generalized definition of drought is a period of abnormally dry weather sufficiently prolonged for the lack of water to cause serious hydrologic imbalance in the affected area. In easier to understand terms, a drought is a period of unusually persistent dry weather that persists long enough to cause serious problems such as crop damage and/or water supply shortages. If the drought is brief, it is known as a dry spell, or partial drought. A partial drought is usually defined as more that 14 days without appreciable precipitation, whereas a drought may last for years. When a drought begins and ends is difficult to determine because rainfall data alone won't tell you if you are in a drought, how severe your drought may be, or how long you have been in drought.

The most commonly used drought definitions are based on meteorological, agricultural, hydrological, and socioeconomic effects:

1. *Meteorological* – A measure of departure of precipitation from normal. Due to climatic differences, what might be considered a drought in one location of the country may not be a drought in another location.
2. *Agriculture* – Refers to a situation where the amount of moisture in the soil no longer meets the needs of a particular crop.
3. *Hydrological* – Occurs when surface and subsurface water supplies are below normal.
4. *Socioeconomic* – Refers to the situation that occurs when physical water shortages begin to affect people.

4.3.8.2. Range of Magnitude

The severity of the drought depends upon the degree of moisture deficiency, the duration, and the size of the affected area. The magnitude of a considered drought event corresponds to the cumulative water deficit over the drought period, and the average of the cumulative water deficit over the drought period's mean intensity.

- Most Severe Drought: 1030-1936 Dust Bowl or 'Dirty Thirties'
- Longest Drought: 1944-1950s: Southwestern United States
- Costliest: Second to the Dust bowl that is estimated to have cost $1 billion in 1930's money is the drought of 1989 and 1999. It is estimated the drought costs somewhere between $80 and $120 billion worth in damage.

4.3.8.3. Spectrum of Consequences

Drought impacts are wide-reaching and may come in different forms, such as economic, environmental, and/or societal. A reduction of electric power generation and water quality deterioration are also potential effects. Drought conditions can also cause soil to compact, decreasing its ability to absorb water, making an area more susceptible to flash flooding and erosion. A drought may also increase the speed at which dead and fallen trees dry out and become more potent fuel sources for wildfires. An ongoing drought which severely inhibits natural plant growth cycles may impact critical wildlife habitats. Drought impacts increase with the length of a drought, as carry-over supplies in reservoirs are depleted and water levels in groundwater basins decline. Impacts from drought can also be exacerbated due to the effects of dust settling on snow, which causes increased solar energy absorption. As a result, snowmelt takes place earlier in the season and runoff magnitudes increase.

The impacts related to early runoff pose problems for many important sectors in Minnesota including agriculture, recreation, tourism, and municipal water supplies. Reservoirs may also be filled to capacity during these constrained runoff periods, causing spills to be necessary. Ideally, to avoid releases of water downstream, water is captured over a longer timeframe with gradual melting of snowpack. Alternatively, dust produced from the hardening and drying of bare soil can also be exposed as vegetative cover decreases due to extended periods of drought.

Although droughts can be characterized as emergencies, they differ from other emergency events in that most natural disasters, such as floods or forest fires, occur relatively rapidly and afford little time for preparing for disaster response. Droughts typically occur slowly, over a multi-year period, and it is often not obvious or easy to quantify when a drought begins and ends.

4.3.8.4. Potential for Cascading Effects

As mentioned, there are many different consequences that can occur from drought. Since droughts typically occur over longer time periods of months, seasons, and years it's possible to start with a few consequences initially, but as the drought persists or worsens, your consequences can start to multiply. This can happen within just the drought hazard itself, but another aspect is adding another hazard on top of or as result of the drought. For example, in drought conditions that have persisted for many months, if you have a rain event occur over a short period of time, the ground will not be able to absorb the moisture quick enough creating a flash flood event. Another common cascading event is the threat and increase of wildfires due to the dry conditions.

4.3.8.5. Geographic Scope of Hazard

Due to natural variations in climate and precipitation, it is rare for all of Minnesota to be deficient in moisture at the same level at the same time. However, single season droughts, and different magnitudes and intensity over some portion of the State are quite common. It is typical for all of Hennepin County to be within a drought at the same time, although possible to have part of Hennepin County in a higher level of drought category than another part of the county.

4.3.8.6. Chronologic Patterns

Drought can occur any time of year, however people mostly think of its effects in the spring and summer months. The onset of summer drought intensity can, and typically, begins with the prior fall and winter being more dry than average.

4.3.8.7. Historical Data

Perhaps the most devastating weather driven event in American History, the drought of the 1920's and 1930's significantly impacted Minnesota's economic, social, and natural landscapes. Abnormally dry and hot growing season weather throughout the better part of two decades turned Minnesota farm fields to dust and small lakes into muddy ponds. The parched soil was easily taken up by strong winds, often turning day into night. The drought peaked with the heat of the summer of 1936, setting many high temperature records that still stand today.

One of the most significant droughts to affect the County was the drought of 1976-1977. The 1976-77 drought was widespread and by some measures was exceeded only by the severity of conditions during the 1930's. In spring of 1976, the general lack of precipitation was statewide. Shallow residential and farm wells began to go dry in June. Some municipalities also were affected. Precipitation continued to be much less than normal for the rest of 1976 and gradually returned to normal during the summer of 1977. Minnesota's State Climatology Office records show the precipitation total for the Twin Cities to be 16.50 inches, well below the 27 inch average (based on the Twin Cities Monthly & Yearly Twin Cities Total Average).

Another severe drought that had an impact on Hennepin County was the drought of 1988. A nationwide event, the Drought of 1988 intensified in June with Minneapolis receiving only 0.22 inches of rain, making it the driest June ever recorded in the metro area. The June average temperature for Minneapolis was 74.4 degrees Fahrenheit, which equaled the second warmest June ever. Statewide temperatures ranged from 6 to 9 degrees above normal. By the end of June most of the state was classified as either in "severe" or "extreme" drought.

The drought continued into July with temperatures six degrees above normal in Minneapolis and rainfall 1.5 to 3 inches below normal. Soil moisture levels reached record lows at most University of Minnesota Experiment Stations. In the Minneapolis area, maximum temperatures of 90 degrees or greater were recorded 17 days, a record high for July. Most locations reported maximum temperatures exceeding 100 degrees at least once during the month.

By August, the drought began to subside but not after severe agricultural damage was caused and several records were broken across Hennepin County and the State of Minnesota including:

- June precipitation averaged 1.40 inches statewide, replacing the old record low of 1.50 inches set in 1910.

- May through August average temperature at 69.7 degrees was nearly 2 degrees higher than the old record set in 1936.
- Minneapolis-St. Paul Airport had 44 days with 90 degrees or more. The old record has been 36 days in 1936.
- The Palmer Drought Index dropped below -7 in northwest Minnesota for the first time since record keeping began at the turn-- of-the-century. The old record had been -6 in September 1934.
- Groundwater levels throughout the state reached new record low levels.
- The Mississippi River at St. Paul reached low levels previously experienced only in 1934 and 1976, prompting the first total sprinkling ban in Minneapolis and St. Paul.

4.3.8.8. Future Trends

In the past few years, there have been several studies published that show to have conflicting conclusions when it comes to trends in past drought occurrence and how the future looks. Part of this is because of the different definitions of drought. Because of the different definitions, a small reduction in the mean of one parameter, can translate into a much larger increase in drought on the other parameters, or definitions.

Many of the computer modeling have shown increased trends in drought occurrences across much of the northern hemisphere. However, results of satellite-based studies along with other observation-based studies conclude there is no significant trend in areas under drought over land in the past three decades.

4.3.8.9. Indications and Forecasting

Drought intensity categories are based on five key indicators and numerous supplementary indicators. The accompanying drought severity classification table shows the ranges for each indicator for each dryness level. Because the ranges of the various indicators often don't coincide, the final drought category tends to be based on what the majority of the indicators show. The analysts producing the final determined category also weighs the indices according to how well they perform in various parts of the country and at different times of the year.

			Range				
Category	**Description**	**Possible Impacts**	**Palmer Drought Index**	**CPC Soil Moisture Model (Percentiles)**	**USGS Weekly Streamflow (Percentiles)**	**Standardized Precipitation Index (SPI)**	**Objective Short and Long-term Drought Indicator Blends (Percentiles)**
D0	Abnormally Dry	Going into drought: short-term dryness slowing planting, growth of crops or pastures. Coming out of drought: some lingering water deficits; pastures or crops not fully recovered	-1.0 to -1.9	21-30	21-30	-0.5 to -0.7	21-30
D1	Moderate Drought	Some damage to crops, pastures; streams, reservoirs, or wells low, some water shortages developing or imminent; voluntary water-use restrictions requested	-2.0 to -2.9	11-20	11-20	-0.8 to -1.2	11-20
D2	Severe Drought	Crop or pasture losses likely; water shortages common; water restrictions imposed	-3.0 to -3.9	6-10	6-10	-1.3 to -1.5	6-10
D3	Extreme Drought	Major crop/pasture losses; widespread water shortages or restrictions	-4.0 to -4.9	3-5	3-5	-1.6 to -1.9	3-5
D4	Exceptional Drought	Exceptional and widespread crop/pasture losses; shortages of water in reservoirs, streams, and wells creating water emergencies	-5.0 or less	0-2	0-2	-2.0 or less	0-2

4.3.8.10. Detection & Warning

At present, the best approach for predicting the development, intensification, and demise of a drought is a two-fold strategy that combines the monitoring of both local water and climate conditions and large-scale wind patterns, including the comparison of current conditions to historical analogues, with the interpretation of computer forecasts. This strategy is employed by both the Monthly and Seasonal Drought Outlooks, which are issued monthly by the National Oceanic and Atmospheric Administration, National Weather Service, and Climate Prediction Center as an operational effort geared toward infusing such advances into drought predictability. Although predicting drought on any scale remains a challenge, progress in understanding global-to-regional scale climate-system phenomena provides hope for improving drought prediction at longer lead times.

Early warning of drought onset, and characterization of its evolving environmental and economic impacts, can be further enhanced by the use of regional-scale early warning systems that promote sustained partnership networks linking meteorological and climatological information providers to water, agriculture, and other private and public management communities.

4.3.8.11. Critical Values and Thresholds

According to the Minnesota Statewide Drought Plan, there are five drought phases/triggers that follow closely to the drought intensity categories. **TABLE 4.3.8A** describes the drought triggers from the Minnesota Drought Plan. These triggers are based on conditions for the different watersheds across the state.

TABLE 4.3.8A Drought Triggers

Drought Phase/Triggers	Conditions
Non Drought Phase	A signification portion of the watershed is not under drought conditions according to the U.S. Drought Monitor.
Drought Watch Phase	A significant portion of the watershed is “abnormally Dry” or in a “moderate Drought”.
Drought Warning Phase	A significant portion of the watershed is in a “Severe Drought”, or from public water suppliers using the Mississippi River, the average daily flow at the USGS gage near Anoka is at or below 2000 cfs for five consecutive days.
Restrictive Phase	A significant portion of the watershed is in an “Extreme Drought”, or for public water suppliers using the Mississippi River, the average daily flow at the USGS gage near Anoka is at or below 1500 cfs for five consecutive days.

Emergency Phase	A significant portion of the watershed is in an "Exceptional Drought", or highest priority water supply needs are not be met, or there are threatened or actual electricity shortages due to cooling water supply shortages, or for public water suppliers in the Twin Cities, the average daily flow of the Mississippi Rover UGSG gage near Anoka is at or below 1000 cfs for five consecutive days.

4.3.8.12. Mitigation

Even though you can't prevent a drought from occurring, and they are hard to predict how long they will actually last, there are ways you can protect from some of the consequences.

- Monitor Drought Conditions: this can provide early warnings for policymakers and planners to make decisions through actions including:
- Monitor Water Supply: This can save water in the long run though the following actions:
- Develop a drought emergency plan
- Develop criteria or triggers for drought-related actions
- Develop agreements for secondary water sources that may be used during drought conditions
- Rotating crops by growing a series of different types of crops on the same fields every season to reduce soil erosion.
- Practicing contour farming by farming along elevation contour lines to slow water runoff during rainstorms and prevent soil erosion, allowing the water time to absorb into the soil.
- Using terracing on hilly or mountainous terrain to decrease soil erosion and surface runoff.
- Planting "cover crops," such as oats, wheat, and buckwheat, to prevent soil erosion.
- Using zero and reduced tillage to minimize soil disturbance and leave crop residue on the ground to prevent soil erosion.
- Constructing windbreaks to prevent evaporation from reclaiming salt-affected soil.
- Collecting rainwater and using natural runoff to water plants.
- Encourage farmers and agriculture interests to obtain crop insurance to cover potential losses due to drought.

4.3.8.13. Response

When drought occurs, the water supplier and community must take action to reduce the demand for water. While increasing water supplies would be of benefit, most such remedies require more than 5 years to plan and construct new reservoirs, canals, and/or groundwater sources. Reducing water demand can result in significant positive effects within only a few days.

Voluntary action from water users can result in up to 25% water use reduction for short periods of time. Mandatory restrictions have resulted in as much as a 40% reduction of water use. This savings effect is directly related to: a) the public's belief that the emergency is real; b) the public clearly understands the actions required to reduce water use; and c) the active enforcement of mandatory water use restrictions. It is very important for water suppliers to understand the public seldom sustains the voluntary water conservation levels more than a few months. Drought response actions, even mandatory water use restrictions are designed to be suspended once the drought is deemed over. Drought response programs and water efficiency programs are two very different actions for two different problems.

Water efficiency programs are designed to effect long-term (even permanent) water use reductions; drought response is designed to solve short term water supply deficits. Water efficiency programs can reduce the impact of subsequent droughts, but water efficiency strategies continue beyond the term of a drought. Water efficiency planning is usually based on the economics of avoided costs or least cost planning. Drought response is meant to solve an emergency supply shortfall; thus, does not always need to be justified by avoided costs.

4.3.8.14. Recovery

Like all disasters, recovery from drought can takes months to years to return to a state of normalcy. On August 7, 2012, President Barack Obama called for an "all hands on deck" approach to the drought at a White House Rural Council meeting. At the same meeting, the President asked that USDA take the lead in coordinating the Federal effort to help with drought response and recovery.

To support this collaboration across multiple federal agencies, the concepts and organizing principles of the National Disaster Recovery Framework (NDRF) were leveraged to promote a more integrated and cohesive response to drought. Based on the input received in the Drought Recovery Regional Meetings, the NDRF team identified “big bucket” issues to organize Federal resources identified across all applicable departments and agencies. These included technical assistance, grant programs, loan programs, and information resources. **TABLE 4.3.8B** shows resources for short-term and long-term recovery. The short-term section provides links to agencies providing relief resources and information. The long-term recovery section is geared more toward information to aid in mitigation and adaptation but long-term recovery resources are also listed.

TABLE 4.3.8B Agency and Recovery Support

Agency	Short Term Recovery	Long Term Recovery

U.S. Department of Agriculture: provides financial and technical assistance to drought affected areas and services	• The Natural Resources Conservation Service
	• The Rural Development Program
	• The Farm Service Agency
	• Crop Production Losses
	  ◦ Disaster Assistance Programs
	• Natural Resource Protection/Private Lands
	  ◦ Environmental Quality Incentives Program
	  ◦ Emergency Watershed Protection
	• Community Water and Wastewater
		• Crop Insurance
		  ◦ Risk Management Agency
		• Natural Resource Protection/Private Lands
		  ◦ Agricultural Water Enhancement Program
		  ◦ Emergency Watershed Protection - Floodplain Easement
		  ◦ Watershed Protection and Flood Prevention
		  ◦ Wetlands Reserve Program
		  ◦ Conservation Technical Assistance
		• Community Water and Wastewater

Us Department of Interior	• The Recovery Act • The Drought Water Bank	• DOI's Bureau of Reclamation administers the WaterSMART and water and Energy Efficiency Grants that aims to make more efficient use of existing water supplies through water conservation, efficiency and water marketing projects. Funding is also available to promote water use efficiency program projects like rebate programs, irrigation system upgrades, water conservation education programs and to address and improve Best Management Practices.
Environmental Protection Agency		• EPA works with states to manage programs that provide financial assistance for projects that protect public health and water quality. EPA also manages the WaterSense Program, which helps consumers identify water-efficient products, practices and programs.
National Oceanic and Atmospheric Administration	• Endangered Species Act • NIDIS	• Endangered Species Act • NIDIS
Small Business Administration	• Economic Injury Disaster Loans	• Economic Injury Disaster Loans

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4.3.9.	Hazard Assessment: DUST STORM

4.3.9.1. Definition

A dust storm is a strong, violent wind that carries fine particles such as silt, sand, clay, and other materials, often for long distances. The fine particles swirl around in the air during the storm. A dust storm can spread over hundreds of miles and rise over 10,000 feet and can have wind speeds of at least 25 miles per hour. Dust storms usually arrive with little warning and advance in the form of a big wall of dust and debris. A common name for dust storms is Haboob, which comes from Arabic word *habb* meaning wind.

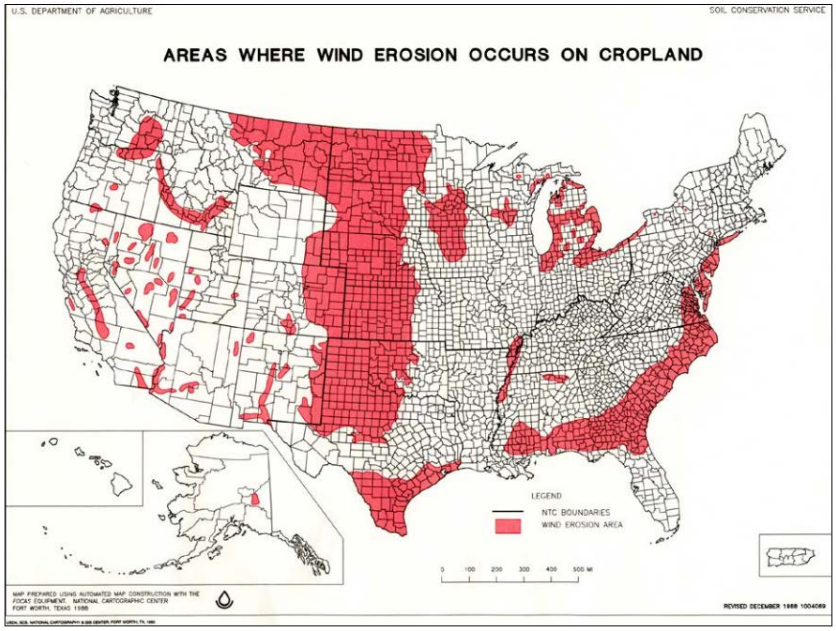
4.3.9.2. Range of Magnitude

There are two main kinds of dust storms; one where the dust is carried along the surface, and the other where dust is lifted high into the atmosphere. Each of these dust storm types can happen individually, or together at the same time. If these two types of storms happen together at the same time, there is the potential for greater magnitude of consequences versus each type individually. Below are a few examples of dust storms from the National Climatic Data Center that have occurred in the United States since 1950.

- Longest Distance: May 17, 2001 Dust from a storm in China traveled across the ocean and deposited dust from Alaska to Florida.
- Most Costly: June 10th, 2013 Humboldt, Nevada, $1.5 million Property Damage
- Deadliest: October 13, 2009 SW S.J. Valley, 3 fatalities

4.3.9.3. Spectrum of Consequences

Dust storms can have environmental, health, social, and economic consequences. Health consequences include poor air quality due to the increase in breathable suspended particles in the air which can be almost an instant consequence with people choking on dust or a consequence from particles suspended over time. Environmental consequence can be dust deposition on the landscape which can cause drying of leaves, and negative growth of plant and damage to crops. Some of the social impacts can be road and aviation accidents due to the poor visibility. Economic impacts can include damage to structures, and roads, costs associated with cleaning of infiltrated dust inside the houses and buildings, costs associated with accidents, material, crop, and production loss. On 75 million acres of land in the United States alone, wind erosion is still a dominant problem, with four to five million acres moderately to severely damage each year.



Many believe that dust storms are not a worry for urban areas. However urban communities are not immune to the harmful effects of dust storms either. One thing that is a concern when a dust storm hits a town or city is power outages and infrastructure damage. Anyone of these two things could have a negative result for a business. Also, there could be extensive damage to computers and communications equipment from the buildup of dust. The dust particles can get into buildings and businesses and work their way inside computers and telecommunications equipment, ruining the delicate technologies on the inside. Again, with many businesses today being dependent on technologies such as computers and communications equipment, this could have a negative impact on commerce.

4.3.9.4. Potential for Cascading Effects

The immediate economic impact of dust storms is significant, but it doesn't rival major natural disasters that destroy entire cities. For instance, the damage due to dust storms in China averages at about $6.5 billion per year. A single major earthquake can do damage to the tune of five times that figure. However, experts argue that the real economic impact of dust storms, particularly those that originate in areas of desertification, is difficult to pin down because of the long-term consequences they have on the livelihood of people who live in the area. When dust storms kick up in agricultural dry lands that are degraded, they remove the topsoil, which causes further desertification. As a result, farmers are forced to watch the topsoil, and their livelihood, literally blow away. This cycle, if gone unchecked, threatens to displace whole communities in some regions.

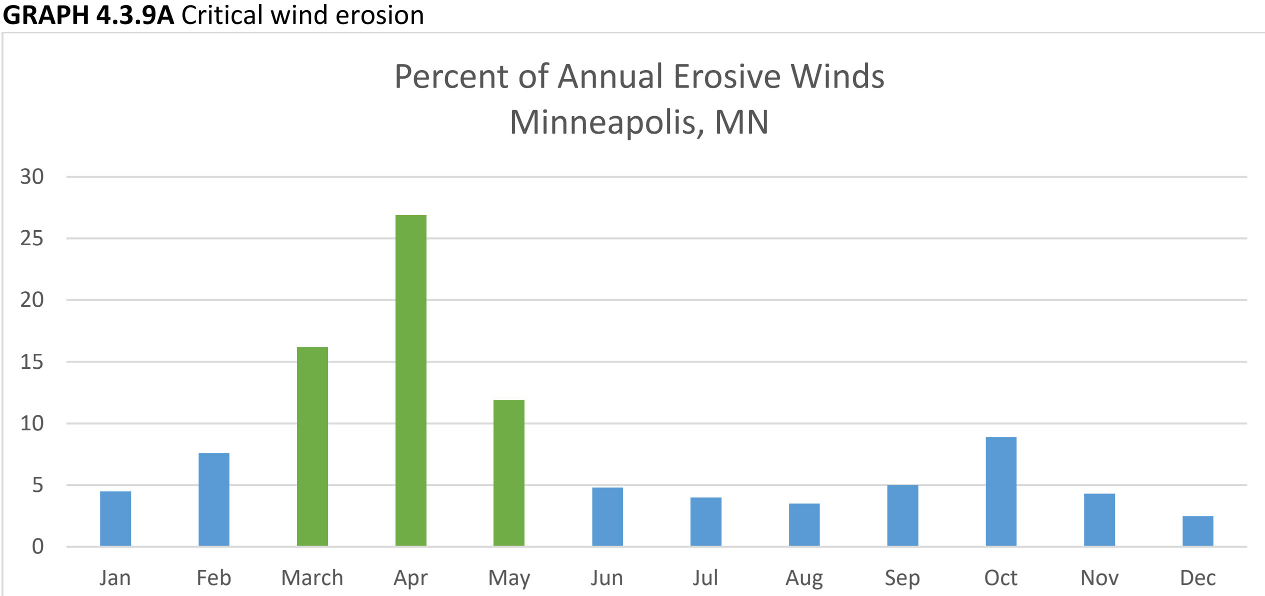
4.3.9.5. Geographic Scope of Hazard

The winds involved with dust storms can be as small as "dust devils" or as large as fast moving regional air masses. Dust storms occur most frequently over deserts and regions of dry soil, where particles are loosely bound to the surface. Dust storms don't only happen in the middle of the desert, however. They happen in any dry area where loose dirt can easily be picked up by wind. Grains of sand, lofted into the air by the wind, fall back to the ground within a few hours, but smaller particles remain suspended in the air for a week or more and can be swept thousands of miles downwind. Dusts storms can reach as high as 10,000 feet with an aerial coverage on the leading edge that can stretch for 100s of miles. However on average, they only travel around 25 to 50 miles.

4.3.9.6. Chronologic Patterns

Dust storms are not common around Minnesota, but they can happen any time of year. Dust storms are typically thought of as most common in Arizona and specifically during the monsoon season. However, when dry conditions are present
GRAPH 4.3.9A shows the critical wind erosion period in Minnesota. It shows that March, April, and May are the periods of the year where agricultural fields are particularly vulnerable to wind erosion, and to extension dust storms, due to higher wind speeds with direction of prevailing wind than normal and low vegetative cover on fields.

GRAPH 4.3.9A Critical wind erosion



4.3.9.7. Historical Data

About the time the Great Plains were settled in the mid-1800s, the land was covered by prairie grasses which held moisture in the soil. By the early 20th century, farmers start to till and plow under much of the prairie grass which is what started the issues with dust storms. It was during the drought of the 1920s that Minnesota saw some of the worst dust storms in its history. During the year of 1924, Minnesota saw unusually high winds and thick dust occurring on the 22, 23, 24, 28, and 31st of January. This occurred again on six dates in February, 15 dates in March, and 19 dates in April. . The climax of the dust storms prevalent during 1924 was reached on May 9-10. Reports from over the State indicate that the storm was probably the most severe of its kind ever experienced. Much seed was uncovered or blown out, especially on light soils, where in extreme cases as much as 90 percent was reported lost.

4.3.9.8. Future Trends

There is no current research available on the direct effects of future climate conditions on the incidence of dust storms. However, because drought conditions have the effect of reducing wetlands and drying soils, droughts can increase the amount of soil particulate matter available to be entrained in high winds, in particular where agriculture practices include tilling. This correlation between drought conditions and dust storms means that an increase in future droughts could increase the incidence of dust storms, even though the drought is not directly related to the directly to the dust storm.

4.3.9.9. Indications and Forecasting

Dust storms move quickly. Other than seeing a wall of brown dust approaching in the distance, there is not much warning before a dust storm arrives. However, they usually precede thunderstorms. So if conditions have been dry, and one can see a large thunderhead cloud and feel the wind is picking up, one can expect dust to be blowing with the possibility of dust storm type reduced visibilities and consequences. Dust storm events are caused by different weather systems showing different intensities and identifiable characterizes in observational systems.

There are four dust storm generation types: frontal, meso- or small-scale, disturbances, and cyclogenesis. Key features of cold front-induced dust storms are their rapid process with strong dust emissions and a large affected area. Frontal dust storms typically last 3-5 hours with wind speeds of 36-83 mph and typically affect an area of 7,700 to 77,000 square miles.

Meso- or small-scale dust storms are the most common type of dust storm including thunderstorms, convections along dry lines, gusty winds cause by high pressure, and more. The most common occurrence are thunderstorms in which the organized outflow from the downdrafts of decaying thunderstorms blow dust plumes. These storms can typically last 2-5 hours with winds from 53 to 78 mph. They produce the highest level of particle emission over a limited area, typically 2,000 to 6,000 square miles.

The third type of dust storms are caused by tropical disturbances. These typically show strong concentration of dust in the air and last longer than frontal and meso- or small scale at 3-7 hours with wind speeds 30 to 58 mph. The typical area covered is just 200 to 4000 square miles.

The last type of dust storm occurs from cyclogenesis which is the development of strengthening or a lower pressure area. Dust storms from cyclogenesis typically last longer than the others at 4-21 hours with wind speeds 38 to 65 mph because cyclogenesis tends to be stationary. These storms typically affect and area of 4000 to 31,000 square miles.

4.3.9.10. Detection & Warning

As mentioned earlier, there is not a lot of indication for dust storms besides knowing the current conditions that may present the storm from occurring. However, with each of the types of dust storms mentioned above, there is never always a dust storm when those conditions are present. The National Weather Service in Chanhassen does not have a specific definition for when they would issue a blowing dust advisory or dust storm warning. In fact, The NWS Office in Chanhassen has never issued a blowing dust advisory or dust storm warning. However, the Grand Forks National Weather Service does. The Blowing Dust Advisory is issued when widespread visibilities are at or below 1 mile but above ¼ mile due to blowing dust for any extended period of time. The Dust Storm Warning is issued during prolonged dry periods when strong winds can produce widespread visibilities in blowing dust at or below ¼ mile for any extended period of time.

4.3.9.11. Critical Values and Thresholds

The blowing dust advisory conditions, visibilities at or below 1 mile, and dust storm warning, visibilities less than ¼ mile, are the two critical values when it comes to warning the public for public safety concerns. Among those concerns are health concerns when dust particles are inhaled. The particles that are small enough to be inhaled are known as PM10 which are particulate matter less than 10 microns in size or smaller.

4.3.9.12. Mitigation

The effects of sand and dust storms can be reduced by using a number of health & safety measures and environmental control strategies. Large-scale sand and dust storms are generally natural phenomena and it may not be always practicable to prevent it happening. However, control measures can be taken to reduce its impacts.

To reduce the consequences of dust events that may not reach dust storm criteria, cities can take appropriate control of dust raising factors such as increasing the vegetation cover where possible by the use of native plants and trees as buffer. These can reduce wind velocity and sand drifts at the same time of increasing the soil moisture.

Some health and safety measures that should be taken to minimize the adverse impacts due dust storms can be alerting vulnerable populations, using dust masks, and restricting outdoor activities and staying inside when dust storms are occurring.

Mitigation strategies to reduce wind erosion from dust storms are lumped into two major categories:

reduce the wind force at the soil surface and create a soil surface more resistant to wind forces. Some of these strategies are standing residues, planting perpendicular to prevailing winds, windbreaks, grass barriers, strip cropping, or clod-producing tillage.

4.3.9.13. Response

One of the most important things to be done during the initial response is to make sure that people are safe. The role of Hennepin County Emergency Management is to coordinate resources that our municipalities may need to accomplish all response needs.

4.3.9.14. Recovery

It is important to note that conditions and consequences from a dust storm may linger longer that one can see to the naked eye. There may be lingering dust in the air after a dust storm so the first step to recovery is to continue to avoid breathing in outdoor air for hours after a storm passes. From an emergency management perspective, assessing the amount of property damage, preparing a list of specific damage to property and buildings, and agriculture damage are top on the list to start the recovery process.

4.3.9.15. References

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4.3.10.	Hazard Assessment: COLD, EXTREME

4.3.10.1. Definition

The term extreme cold can have varying definitions in hazard identification. Generally, extreme cold events refer to a prolonged period of time (days) with extremely cold temperatures. An extreme cold event to the National Weather Service can refer to a single day of extreme or record-breaking day of sub-zero temperatures. The extreme cold definition also depends on the area you live. In southern regions relatively unaccustomed to winter weather, near freezing temperatures are considered extreme cold. In the North, extreme cold means temperatures well below zero.

When defining extreme cold one also must mention wind chill. The wind chill temperature is an apparent temperature, or how cold it feel to people when outside. Wind chill is based on the rate of heat loss from exposed skin caused by wind and cold. As the wind increases, it draws heat from the body, driving down skin temperature and eventually the internal body temperature.

Wind Chill Chart

	Temperature (°F)																	
Wind (mph) / Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times: 30 minutes | 10 minutes | 5 minutes

$$\text{Wind Chill (°F)} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where, T=Air Temperature (°F) V=Wind Speed (mph)

Effective 11/01/01

4.3.10.2. Range of Magnitude

- Lowest Temperature in MN: -60 (Feb 2, 1996: St. Louis County)
- Lowest Temperature in Hennepin County: -41 (Jan 21, 1888)
- Lowest Wind Chill in MN: -71 °F with new formula and -100 °F with old formula (Jan 9&10, 1982)
- Lowest Wind Chill in Hennepin County: -6-73 °F with the new formula and -87 °F with the old formula. (Jan 22, 1936)
- Lowest Maximum Temperature for Hennepin County: -20 (Jan 15, 1988)
- Longest period temperature below 32 degrees in Hennepin County: 66 Day 16 Hours (8PM Dec 18, 1977 through 11 AM Feb 23, 1978)
- Longest Period temperature below 0 degrees in Hennepin County: 7 Days 18 hours (8 PM Dec 31 1911 through 10 AM Jan 8 1912)

4.3.10.3. Spectrum of Consequences

Extreme cold temperatures have well known impacts on human health. On average, the United States sees 29 cold weather related fatalities each year. In 2014, 43 deaths were accounted for because of cold weather and in the past 10 years, Minnesota has had 20 cold related deaths.

Human and animal exposure to cold temperatures, whether indoors or outside, can lead to serious or life-threatening health problems such as hypothermia, cold stress, frostbite or freezing of the exposed extremities such as fingers, toes, nose and ear lobes. Hypothermia occurs when the core body temperature is < 95°F. If persons exposed to excessive cold are unable to generate enough heat (e.g., through shivering) to maintain a normal core body temperature of 98.6°F, their organs can malfunction. When brain function deteriorates, persons with hypothermia are less likely to perceive the need to seek shelter. Signs and symptoms of hypothermia (e.g., lethargy, weakness, loss of coordination, confusion, or uncontrollable shivering) can increase in severity as the body's core temperature drops. Extreme cold also can cause emergencies in susceptible populations, such as those without shelter, those who are stranded, or those who live in a home that is poorly insulated or without heat (such as mobile homes). Infants and the elderly are particularly at risk, but anyone can be affected.

Damage to structures due to extreme cold events is relatively low. Freezing pipes can be the largest problem. Extended periods of cold weather can increase the potential for frost depth problems. The depth to which soils freeze and thaw is important in the design of pavements, structures, and utilities. Increased depth of frost can also delay the frost thaw in the spring which would cause those in agriculture a later start to their season, which may lead to less yield of crops. Broken water mains can put significant demands on municipal public works departments.

4.3.10.4. Potential for Cascading Effects

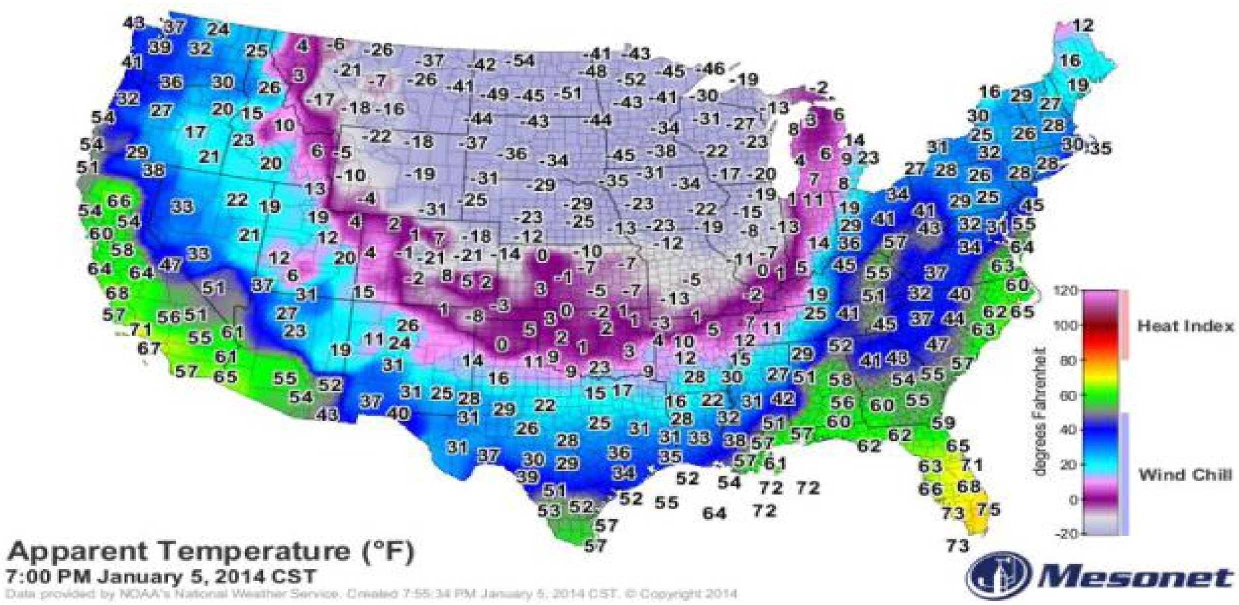
Extremely cold temperatures often accompany a winter storm, so individuals may have to cope with power failures and icy roads. Although staying indoors as much as possible can help reduce the risk of car crashes and falls on the ice, individuals may also face indoor hazards. Many homes may become too cold either due to a power failure or because the heating system is not adequate for the weather. The use of space heaters and fireplaces to keep warm increases the risk of household fires and carbon monoxide poisoning.

During cold months, carbon monoxide may be high in some areas because the colder weather makes it difficult for car emission control systems to operate effectively. Carbon monoxide levels are typically higher during cold weather because the cold temperatures make combustion less complete and cause inversions that trap pollutants close to the ground reducing air quality.

4.3.10.5. Geographic Scope of Hazard

Extreme cold is typically associated with the northern states in the winter. However, extreme cold conditions can occur as far south as Texas. As mentioned in the definition, the social impact or where/how the public is accustomed to cold weather plays a factor in what is called extreme cold for a specific geographical area. **GRAPHIC 4.3.10A** shows an example from 2014. You can see extreme cold apparent temperatures for the majority of the central United States.

GRAPHIC 4.3.10A



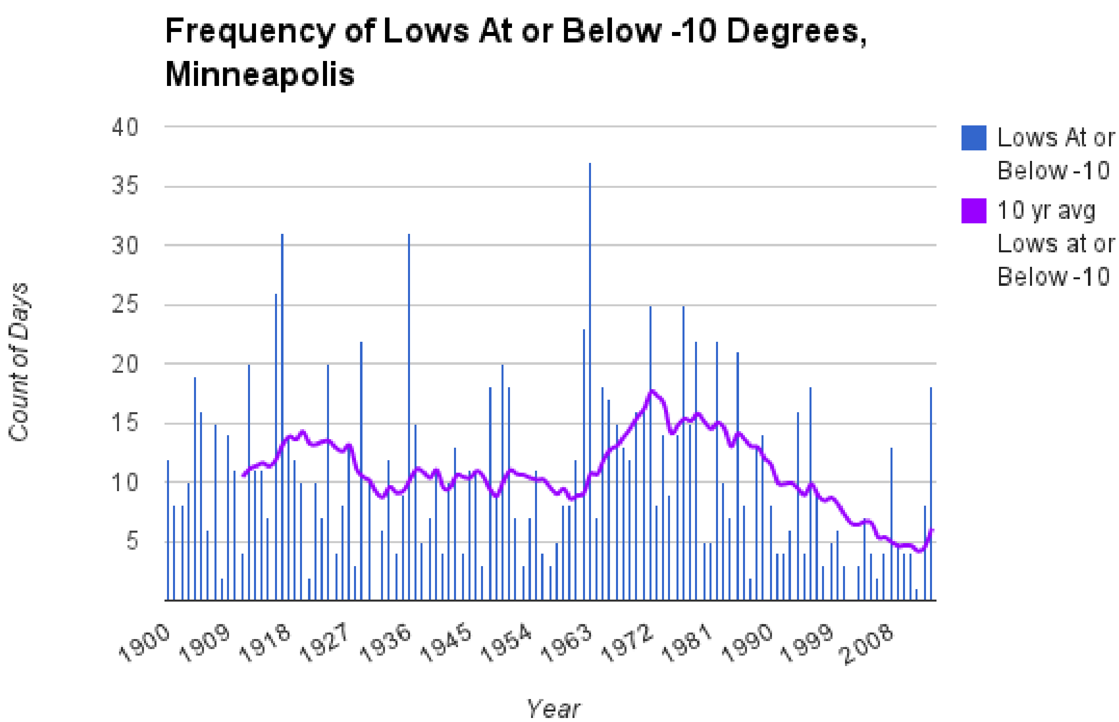
4.3.10.6. Chronologic Patterns

Extreme cold outbreaks occur most commonly during the December, January, February months of the year.

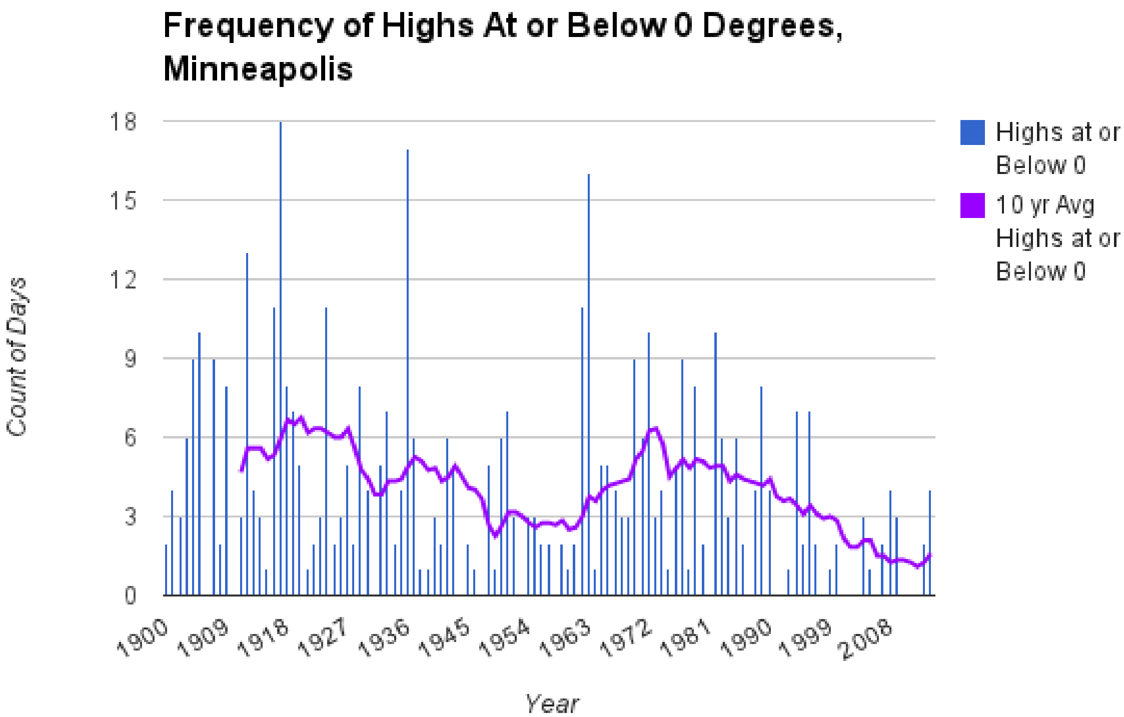
4.3.10.7. Historical Occurrence

Extreme cold is a regular occurrence in Minnesota and in Hennepin County. **GRAPHICS 4.3.10B** and **4.3.10C** shows historically the frequency of lows at or below -10^{o}F and highs at or below 0 degrees in Hennepin County.

GRAPHIC 4.3.10B



GRAPHIC 4.3.10C



What is the coldest wind chill ever seen in the Twin Cities or Minnesota? The answer can be a little tricky because on November 2001 the formula on how to calculate the wind chill was changed. Perhaps the coldest wind chill the Twin Cities has ever seen was -67°F with the new formula (-87°F with the old formula) back on January 22nd 1936. The temperature was -34°F with a wind speed of 20mph. All traffic in the Twin Cities was severely hampered and a number of fatalities were caused by the cold. Without a lengthy state-wide wind record, it is difficult to say when was the coldest statewide wind chill. There are some candidate dates though besides January 22, 1936. On January 9th and 10th, 1982 temperatures of -30°F and winds of around 40mph were reported in Northern Minnesota. This would translate to -71°F by the new formula (-100°F by the old formula.)

A few other notable extreme cold events are:

1989 Feb 3:

- At 6:00 AM in the Twin Cities the air temperature was -22°F with a wind speed of 17mph, creating a wind chill temperature of -49°F (by the 2001 formula).

1994

- On January 13, 1994 an arctic air mass settled over Hennepin County. From January 13 to January 19, true air temperatures dropped from -10°F on January 13 to -27°F on January 19. The high temperature on the January 18 was -16°F. Morning air temperature readings were -26°F in the Twin Cities at 9am with a wind chill temperature of -48°F (by the 2001 formula). The University of Minnesota on the Twin Cities campus closed on the 18th due to the cold and Governor Arne Carlson closed all public schools.

1996

- On January 31, 1996, some of the coldest weather to ever hit Hennepin County settled over the area and remained entrenched through February 4. Minneapolis set three new record low temperatures as well as Minnesota recording the coldest day on record on February 2. A mean temperature of -25°F was measured that day with a high of -17°F and a low of -32°F below zero. This was within two degrees of tying the all-time record low temperature set in the Twin Cities and the coldest temperature recorded this century. On the same date that the Minnesota state record minimum temperature record was set on February 2, 1996 (-60°F near Tower), Governor Arne Carlson cancelled schools for cold a second time. In the Twin Cities at 6am February 2, 1996 the air temperature was -30°F with a wind chill temperature of -48°F (based on the 2001 formula).

- Another extreme cold event took place on December 24, 1996. A strong low pressure system that deposited heavy snow over northern Minnesota also brought down very cold Canadian air. Temperatures fell to 15 to 35 degrees below zero. In addition, the high temperature on Christmas Day in Minneapolis was only -9°F. Combined with the record low temperature that morning of -22°F, the mean temperature for Christmas Day was -16°F. Christmas Day, 1996 set a new record for being the coldest Christmas Day on record for the Twin Cities metro going back to when modern day records began in 1871. The temperature in Minneapolis fell to -27°F.

2004

- The first wind chill warning that was issued for the Twin Cities under the new wind chill temperature formula established in 2001 was the arctic outbreak of January 29-30, 2004. The coldest wind chill observed in the Twin Cities during that period was -43°F at 8:00 AM on January 30, 2004.

2006

- In the wake of a winter storm on February 17, 2006, strong high pressure moved in and created strong winds and dangerous wind chills. The coldest wind chill seen at the Twin Cities International Airport was -34°F. The coldest wind chill found statewide was -54°F at Thief River Falls.

2014

- Governor Mark Dayton cancelled K-12 public schools statewide on Monday January 6th, 2014 due to extreme wind chills that were forecasted well in advance. The coldest wind chill temperature in Minnesota was -63°F at Grand Marais Airport at 9:00 AM with a -31°F air temperature and a 21mph wind. The coldest wind chill temperature in the Twin Cities was -48°F at 5:00 AM with an air temperature of -22°F and a 15mph wind. Many schools also cancelled classes the following day as well. The wind chill at 4am January 7th was -28°F at the Twin Cities International Airport with an air temperature of -14°F and a wind of 6mph. Statewide the coldest wind chill was -50°F reported at Duluth at 4:00 AM with an air temperature of -23°F and a west wind of 16mph.

- Schools were cancelled at many locations again on Thursday, January 23. The coldest wind chill in the Twin Cities on January 23 was at 2:00 AM with a wind chill of -37°F with an air temperature of -14°F and a NW wind of 15mph. The coldest statewide wind chill was -51°F at Park Rapids at 6am with an air temperature of -33°F and as wind of 6mph

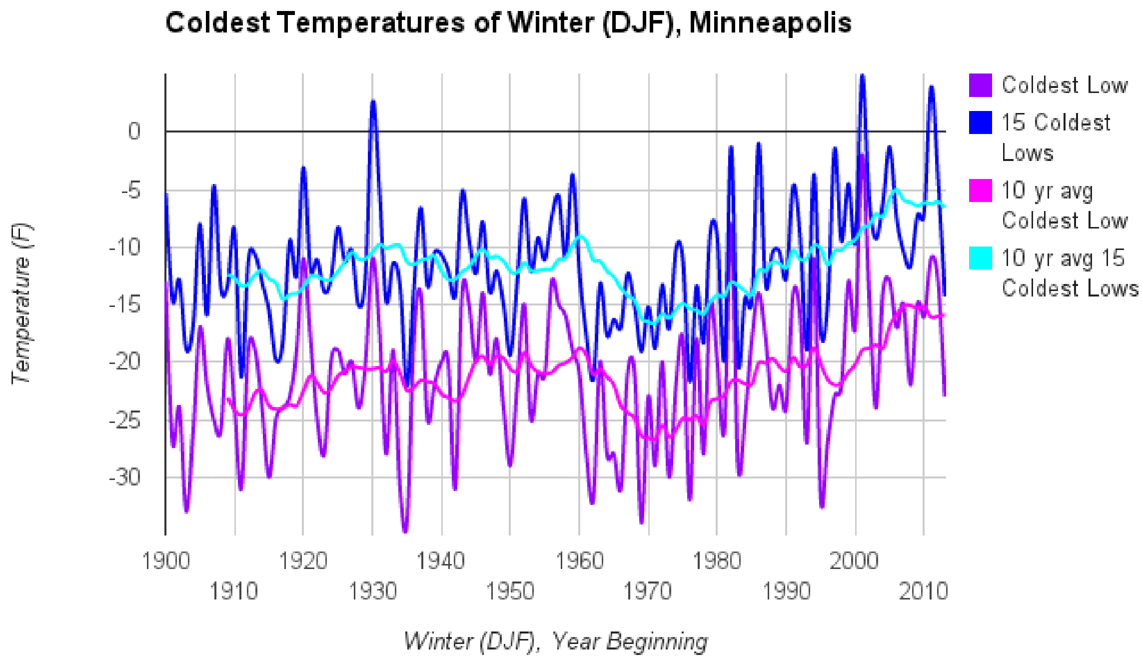
- Schools were cancelled for a fourth day across the Twin Cities on January 27 as well. Classes were also canceled for the day for the University of Minnesota. The coldest wind chill in the Twin Cities was -39°F at 4:00 AM (-13°F air temp and wind NW 20mph). The coldest wind chill statewide was -53°F degrees at the Grand Marais Airport at 8:00 AM (-26°F air temp, wind NE 16mph).

- Schools were cancelled once more across the Twin Cities on Tuesday January 28th. University of Minnesota classes were cancelled in the morning. The coldest wind chill in the Twin Cities was -29°F at 9am with an air temperature of -12°F and a wind speed of 8mph. The coldest wind chill in the state was -52°F at Fosston at 7:00 AM with air temperature of -33°F degrees and a wind speed of 7mph from the south.

4.3.10.8. Future Trends

In Minnesota, there are climate change signals showing the loss of formerly normal cold temperatures. That is saying that the coldest day of the year has warmed by about 8°F since the early 20th century and the 15 coldest days have warmed by about 7° F over the same period. **GRAPHIC 4.3.10D** shows this warming period of coldest temperatures from about 1970 forward. This means the coldest high temperatures have warmed dramatically since 1970 and are now warmer than at any other time on record. In addition, the high temperatures at or below zero have become much less common in recent years and may soon be the exception, rather than the rule.

GRAPHIC 4.3.10D



While temperatures during our winter months seem to be warming, and as mentioned high temperatures at or below zero have become much less common in recent years, this does not mean we will not be seeing any extreme cold events in the future.

4.3.10.9. Indications and Forecasting

The National Weather Service is responsible for forecasting all extreme cold events for Hennepin County. Typically extreme cold events occur when a continental polar or continental arctic air mass makes its way down over Minnesota. These are air masses that originate over the ice and snow-covered regions of northern Canada and Alaska where long, clear nights allow for strong cooling of the surface. Extreme cold typically occurs with or following a low pressure. As the system passes off to the east, continental polar or continental arctic air gets pulled down on the backside of the low pressure.

4.3.10.10. Detection & Warning

The National Weather Service issues Wind Chill Advisories, Watches, or Warnings based on the following forecasted criteria:

- **Wind Chill Advisory:** Widespread wind chill values around -25°F or colder, with at least a 5 to 10 mph wind.
- **Wind Chill Watch:** Widespread wind chill values around -35°F or colder, with at least a 5 to 10

mph wind.

- **Wind Chill Warning:** Widespread wind chill values around -35o or colder, with at least 5 to 10 mph wind.

4.3.10.11. Critical Values and Thresholds

Depending on where you live in the state, there are different critical values that related to the advisories, watches, and warnings listed above. The critical wind chill values for Hennepin County are -25°F and -35°F. It is at -25°F that exposed skin can start to see frostbite in 15-30 minutes of being outside. At -35°F, it takes just 10-15 minutes for exposed skin to be susceptible to frostbite.

4.3.10.12. Mitigation

Education and Awareness Programs

- Educating the public regarding the dangers of extreme cold and steps they can take to protect themselves when extreme cold occurs.
- Organize outreach to vulnerable populations, including establishing and promoting accessible heating centers in the community.
- Encourage utility companies to offer special arrangements for paying heating bills.
- Educate homeowners and builders on how to protect their pipes including locating water pipes on the inside of building insulation or keeping them out of attics, crawl spaces, and vulnerable outside walls.
- Informing homeowners that letting a faucet drip during extreme cold weather can prevent the buildup of excessive pressure in the pipeline and avoid bursting.

4.3.10.13. Recovery

Depending on the consequences that occurred during the extreme cold event, recovery can be short or long. Recovery time from frostbite depends on the extent of tissue that was affected. It can take sometimes up to three months to determine the extent of the damage. When it comes to recovery from deep frost depth, it can take months to years to recover from consequences of broken water mains or broken roadways, or crop yield.

4.3.10.14. References

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4.3.11.	Hazard Assessment: WINTER STORM, BLIZZARD, EXTREME SNOWFALL

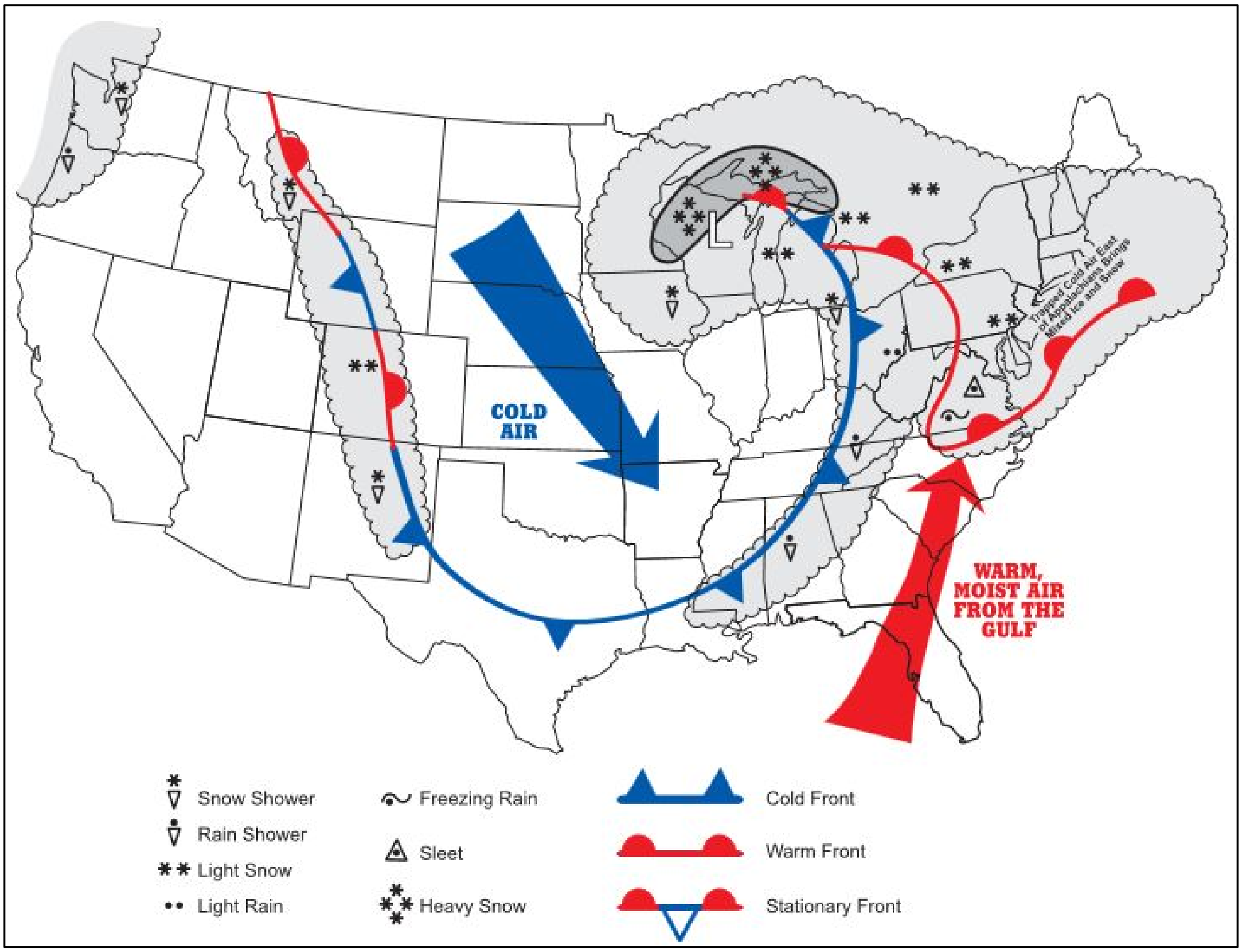
4.3.11.1. Definition

Cars on Excelsior Boulevard after 1940 "Armistice Day Blizzard." Courtesy MN Historical Society

Winter storms produce intense snowfall rates and large accumulations that can immobilize entire regions and paralyze cities, stranding commuters, closing airports, stopping the flow of supplies, and disrupting emergency and medical services. The weight of snow can cause roofs to collapse and knock down trees and power lines. Homes, farms, and businesses may be isolated for days. The cost of snow removal, repairing damages, and the loss of business can have severe economic impacts on counties and municipalities. In Hennepin County, virtually all winter storms are generated by the convergence of moisture and cold temperatures found along the front, left, and left-rear side of low pressure systems.

Blizzards represent the most dangerous class of winter storms, combining strong winds with falling or freshly fallen snow to reduce visibility dramatically. Technically, they are defined as three hours or more of sustained winds or frequent gusts in excess of 35 mph in falling or blowing snow, visibilities reduced to 1/4 mile or less. The strong winds create deadly whiteout conditions that bring traffic to a standstill, enabling the wind-driven snow to form enormous drifts that are impossible for many vehicles to penetrate. In addition, the strong winds are often accompanied by falling temperatures and low wind chills, subjecting stranded motorists to life-threatening conditions that may persist for 24 hours or more. Lastly, the strong winds of blizzards exert additional stress upon structures if they were already straining under the load of heavy snow.

All winter storms have some combination of cold air, moisture, and lifting mechanisms that turn the moisture into precipitation. The vast majority of winter storms affecting Hennepin County are associated with extratropical cyclones (low-pressure systems). Typically the heaviest snow and blizzard conditions are found on the left side of the path of the storm system.



Typical weather pattern associated with major winter storms in Minnesota and Upper Midwest. Source NOAA, http://www.nws.noaa.gov/os/winter/resources/Winter_Storms2008.pdf

Unfortunately, blizzards are not consistently tracked and are difficult to diagnose retroactively. Moreover, the vast majority of major winter storms in Hennepin County have not prompted Blizzard Warnings. In fact, the last NWS-issued Blizzard Warning in Hennepin County was on November 1-2, 1991, during the infamous Halloween Blizzard. However, many winter storms have produced Blizzard warnings in neighboring counties, along with winds in Hennepin County that significantly compounded the impacts from accumulating snow. Therefore, to avoid confusion and the mis-attribution of impacts, in this report, *a blizzard is any accumulating snow event known to have a significant wind-driven and blowing snow component*.

While many winter storms produce sleet and/or freezing rain, Hennepin County Emergency Management recognizes these as distinct hazards and will cover them separately.

4.3.11.2. Range of Magnitude

A given location in Hennepin County sees 24-hour snowfall totals in excess of six inches 1-2 times per year on average, though there have been years with five or more such events. Blizzards, on the other hand, recur approximately once every 3-4 years in western and northwestern parts of the county, and every 6-8 years inside the 494-694 loop. It should also be noted that blizzard conditions can occur without large snowfall accumulations. These "ground blizzard" situations are most common in rural Minnesota, but can occur in open areas of Hennepin County, west of the I-494 corridor, and especially west of MN highway 101.

Duration	Largest value at MSP	Date
Calendar-day snowfall	18.5"	11/1/1991
24-hour snowfall	21.1"	10/31-11/1/1991
2-day snowfall	26.7	10/31-11/1/1991
3-day snowfall	34.6"	01/20-22/1982
5-day snowfall	39.1"	01/20-24/1982
Monthly total	46.9"	November 1991
Duration	**Largest value in Minnesota**	**Date**
24-hour snowfall	36" (near Finland, Lake County)	01/07/1994
Snowstorm total	47" (near FInland, Lake County	01/06-08/1995
Monthly total	66" (Collegeville)	March 1965

4.3.11.3. Spectrum of Consequences

***Outdoor life safety hazards**:* Severe winter storms and blizzards are accompanied by falling temperatures and dangerous wind chills. Persons caught outside unprepared can face disorientation, frostbite, hypothermia, and death. 25% of winter storm casualties occur among those caught outside in the storm.

Power/utilities: Heavy snow can cause power outages from direct loading on electrical wires, and more commonly from indirect sources, for example when tree limbs become overloaded with snow and fall onto wires. Heavy, wet snow in particular can cause widespread power outages, and strong winds exacerbate this impact. The duration of service outages is typically related to the complexity of the outage pattern, along with the ability of crews to get to repair sites. Thus, high-volume, heavy, wet, wind-driven snow events are associated with higher outage numbers and longer service delays.

***Structural failure**:* Heavy snow will can cause roof collapse, not just at residences, but at larger commercial facilities as well. Large roof spans lacking consistent support are especially vulnerable. The former Hubert H Humphrey Metrodome Stadium in Minneapolis failed three separate times from excessive snow loads causing the Teflon canopy to tear.

***Transportation**:* By far the greatest and most common impacts from winter storms in Hennepin

County are to the transportation infrastructure, but there is no strict threshold above which heavy snow is guaranteed to produce a particular impact. Stranded vehicles and snow removal costs increase with greater accumulations, but accidents and spinouts are often a function of prior road conditions, driver preparedness and awareness, and the consistency of the accumulating snow. For instance, from January 31- February 2, 2004, a well-forecast series of winter storms produced widespread 8-11" snowfall totals across the Twin Cities, but a relatively small impact, owing to preparedness, and the generally fluffy nature of the snow. By contrast, a much smaller event on March 8 that same year, produced only 1-3 inches, but did so unexpectedly and within a 2-hour window. This "surprise" event caused hundreds of spinouts and accidents, and forced the closure of the I-94 exit at 280.

The NWS estimates that 70% of winter storm related casualties result from vehicular accidents. Heavy snow impedes traffic, creates hazardous travel conditions, and requires plowing and surface treatment to keep roads passable. It also significantly reduces visibilities, which compromises driver reaction times. In blizzard conditions, the effect of wind further restricts visibilities, often to zero, and can easily disorient drivers. Stranded drivers and those forced to leave their vehicles because of accidents are often directly exposed to the harsh conditions outside their vehicles, and can quickly find themselves in a life-threatening situation.

Airports frequently experience significant delays, and it is common for all runways to close for a time during major winter storms.

4.3.11.4. Potential for cascading effects

Heavy snow and blizzard conditions can occupy a large portion of any strong, cold-season extratropical cyclone, and as a result can precede, follow, or be accompanied by a wide range of weather conditions. Situational awareness is key to understanding if and how the effects of winter storm conditions will be compounded by the following hazards.

Flooding: Unusually intense and/or repetitive snowfalls can sap local governments of their resources, as crews put in long hours to maintain roads, and clear debris. As the heavy snow melts, it poses flooding risks for area streams, basements, low-lying intersections and other areas prone to ponding. Heavy rainfall events falling onto or just after the melting of a large snowpack pose immediate flooding threats, as soil storage capacity is often very limited. In April of 2001, heavy rains in southern Minnesota caused considerable flooding, after an unusually long and snowy season left a large snowpack and saturated soils. The longer a snowpack persists into spring, the greater the likelihood an extreme rainfall event will interact with it.

Extended power outages: A severe winter storm that knocks out power becomes much more dangerous as the time to restore service increases. This is especially true of storms that are followed by a rapid drop in temperatures. Residences and facilities dependent on electrical power for heating or heat distribution can become dangerously cold within hours of power loss.

Moreover, it is not uncommon for a heavy snowfall event or blizzard to proceed shortly after a major ice storm. In these cases, the ice produces the initial critical loading, but then the snow and/or wind acts as the “final straw,” resulting in severe and widespread power outages. In these situations, the snowstorm or blizzard is just another link in a chain of cascading hazards already in progress.

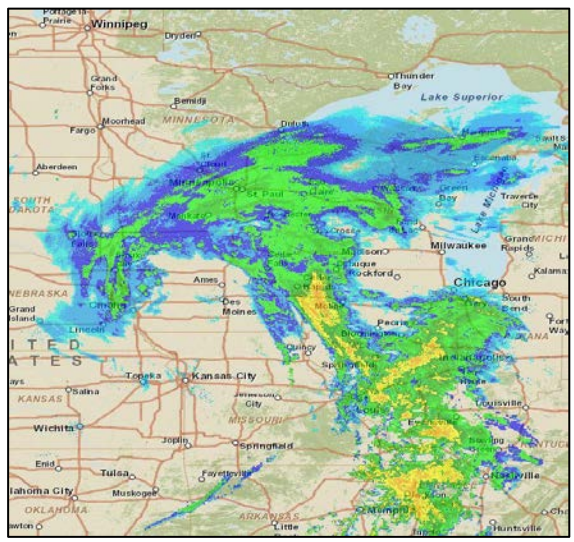
Overexertion: Snow removal after a major event often results in a casualty spike related to overexertion resulting from attempting to dislodge stranded vehicles and clear snow from sidewalks and driveways. It is a major cause of winter-related fatalities in the US.

Severe weather: In rare situations, a major winter storm can follow a significant severe weather event. An infamous tornado-blizzard combination affected Janesville, WI on November 11, 1911. The tornado killed nine people, and was followed almost immediately by a historic cold front that brought blizzard conditions within 1-2 hours of the tornado’s passage, as temperatures fell from the 60s and 70s into the teens. On April 26, 1984, a strong, killer tornado hit Minneapolis and St. Anthony, and was followed within three days by up to 10 inches of snow. Most recently, on March 31, 2014, a confirmed tornado struck near St. Leo in Lyon County MN, while a Blizzard Warning was already in effect.

4.3.11.5. Geographic Scope of Hazard

A given winter storm may affect several hundred thousands of square miles over a period of days, and often will have an instantaneous footprint of 50,000 square miles, under which dangerous winter weather conditions are occurring. The swath of all precipitation including rain and thunderstorms may cover an area the size of several Midwest states.

Winter storms have occurred in virtually every part of the US, except for coastal southern California, parts of the Sonoran Desert, and southern Florida. The most severe winter storms are found in the Central and Northern Plains, and downwind of the Great lakes, and along the East Coast. Comparatively, Minnesota experiences storms that generally produce lesser snowfall totals and/or weaker winds.



Extent of precipitation associated with major winter storm on December 11, 2010

4.3.11.6. Chronologic patterns (seasons, cycles, rhythm)

Winter storm season in Minnesota extends from late October through April, with peak frequencies from late-November through mid-March. Historically, February has had the fewest major snowstorms. However, since 2004, February has become remarkably more active, while March has become less so.

4.3.11.7. Historical data/previous occurrence

The Twin Cities has had dozens of major winter storms since the late 19th century, with 25 calendar-day snowfalls of 10 inches or greater, and 26 two-day totals of at least 12 inches (**TABLE 4.3.11A**).

TABLE 4.3.11A Historical 2-day snowfall totals of 12" or greater in the Twin Cities. Events in bold are known blizzards in Hennepin County since 1940.

Date ending	Total (in.)		Date ending	Total (in.)
11/17/1886	13.0		**1/21/1982**	**17.4**
3/12/1899	12.0		**1/23/1982**	**20.0**
3/1/1907	12.0		12/28/1982	16.5
4/28/1907	13.0		4/14/1983	13.6
12/17/1908	12.8		11/28/1983	12.2
1/22/1917	16.0		**3/4/1985**	**16.7**
3/29/1924	12.0		3/31/1985	14.7
3/13/1940	15.6		**12/1/1985**	**15.9**
11/12/1940	**16.7**		**11/1/1991**	**26.7**
3/23/1952	14.1		11/30/1991	14.3
3/12/1962	12.7		3/9/1999	16.0
3/18/1965	12.2		**12/11/2010**	**17.1**
3/23/1966	13.6		2/21/2011	13.8

Additionally, some smaller snowstorms have also produced blizzard conditions in Hennepin County. Notable recent examples include March 1-2, 2007 and February 21, 2014, when 6-12 inches of snow were finished off with 25-40 mph winds. Following are more detailed accounts of some of the area's most noteworthy winter storms.

The Armistice Day storm of November 11, 1940
is the defining blizzard of the 20th century in Minnesota and remains the storm against which all other blizzards in this state are compared. It was a high-impact, high-mortality blizzard affecting a huge swath of Minnesota, Wisconsin, Iowa, and the Dakotas.

The storm began as a low pressure area over Colorado on the morning of November 10, which then swung northeastward and intensified rapidly as it passed over La Crosse and eventually Lake Superior on the 12th.

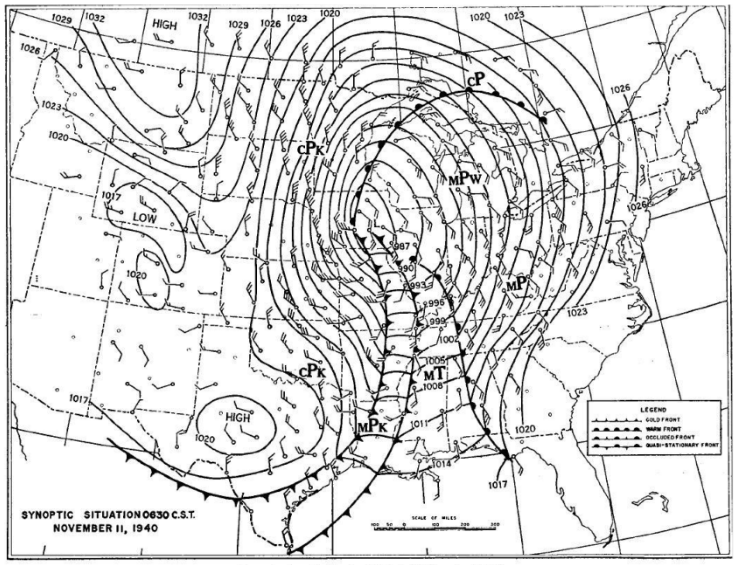


FIGURE 5.—Synoptic situation 0630 C. S. T., November 11, 1940.

Surface pressure chart on November 11, 1940

Initially warm conditions gave way to rapidly falling temperatures, and rain turning to extremely heavy windswept snow. Winds were sustained above 30 mph over much of Minnesota, with gusts exceeding 65 mph in some areas. Snowfall rates at times were as high as three inches per hour. Snowfall totals of 15-25 inches were common across Minnesota, including Hennepin County.

The long duration of the storm, combined with its rapid onset and its severity contributed to extreme losses, including 49 deaths in Minnesota alone- many of whom were stranded motorists who could not navigate the enormous snow drifts that were up to 15 feet high in open sections of Hennepin County. Over a dozen of the dead were hunters who were dressed for pleasant weather and were caught off-guard and stranded on islands in the Mississippi River. One train derailed, two were involved in a head-on collision, and one could not complete its route because of the snow. The regional death toll exceed 150, with many of the non-Minnesota deaths coming from numerous capsized Great lakes vessels.

"Storm of the Century", January 10-12, 1975.

Formed by a then-record-setting low pressure system, this storm only produced 4-8" of snow in the Twin Cities, but hit areas to the west and north much harder. There, hurricane-force winds gusts and blinding snowfall were common, with accumulations of up to 27 inches and drifts of 10-20 feet in open country. Ice accumulated over one inch in parts of southwestern and southern Minnesota, and the combination of ice, heavy snow, and severe winds produced thousands of power and telephone outages.

The storm claimed the lives of 35 Minnesotans, 21 of whom suffered heart attacks. The Red Cross provided food and shelter to over 17,000 people. Despite the heavy losses, the storm was well anticipated and forecasts are credited with keeping the casualty toll in check.

Back-to-Back Record-Breakers, January 20-22, 1982.

A low pressure system interacting with an exceptionally air mass in retreat produced a broad swath of heavy snow over much of Minnesota on January 20. Widespread daily totals of 10-20 inches were common, and the Twin Cities recorded 17.1", which broke the all-time daily snowfall record that had been set during the Armistice Day storm.

As the storm wound down and exited the region on the 21st, a more potent low pressure system emerged from the Colorado Plains. This system intensified and moved into the region on the 22nd, producing heavy snow, sleet, ice, thunder, and blizzard conditions, prompting the closure of interstates 90 and 35 for part of the day. Snowfall totals of 10-20 inches were again common, this time over an even larger area. The Twin Cities recorded 17.2" on the 22nd, breaking the all-time snowfall record that had been set just two days earlier.

The extreme snow loads from these storms—in many cases greater than 30 inches—caused many residential and commercial roof failures.

"Wall of White" blizzard, February 4, 1984.
A fast-moving low-pressure system and cold front charged through Minnesota, producing 2-4 inches of light powdery snow and sustained winds in excess of 40 mph, with gusts as high as 75 mph.

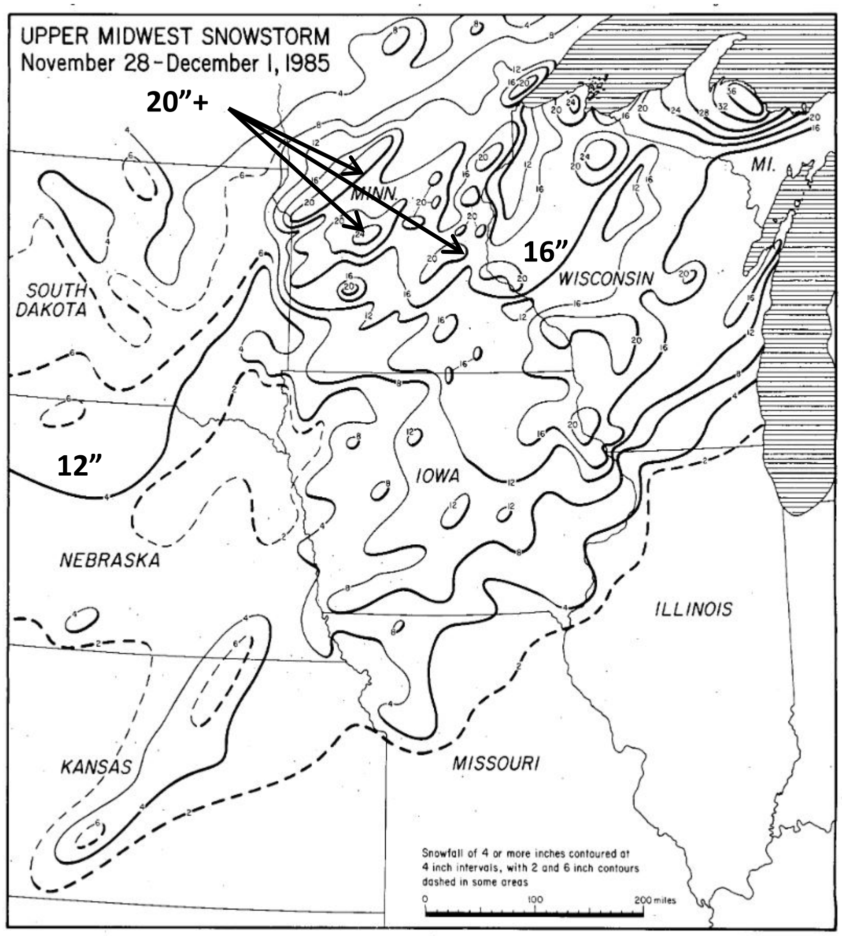
The snow and wind were unexpected and moved southward at up to 50 mph. The sudden onset of the blizzard caused severe traffic problems in rural areas, where visibilities fell to zero and snow drifts covered many roads. Cars stalled in the snow, spun out, and motorists who ventured out were subjected to subzero temperatures and 40-60 mph winds.

The storm killed 21 people in a matter of hours, almost all from exposure, and almost all of whom had been in stranded vehicles. This storm remains the most lethal single weather event in Minnesota in the last 50 years.

Thanksgiving weekend Blizzard, 1985.

An unusually prolonged and widespread winter storm produced several waves of heavy snow over Minnesota, Iowa, Wisconsin and the Dakotas between November 28th and December 1st, 1985.

In the Twin Cities, at least 5 inches on three consecutive days, with each consecutive day producing more snow than the last—this behavior is unprecedented in the area's recorded history, and resulted in three-day totals in excess of 20 inches.



Snowfall pattern, From Nov 28 – Dec 1, 1985, modified from original, courtesy of NOAA/NCDC, December 1985.

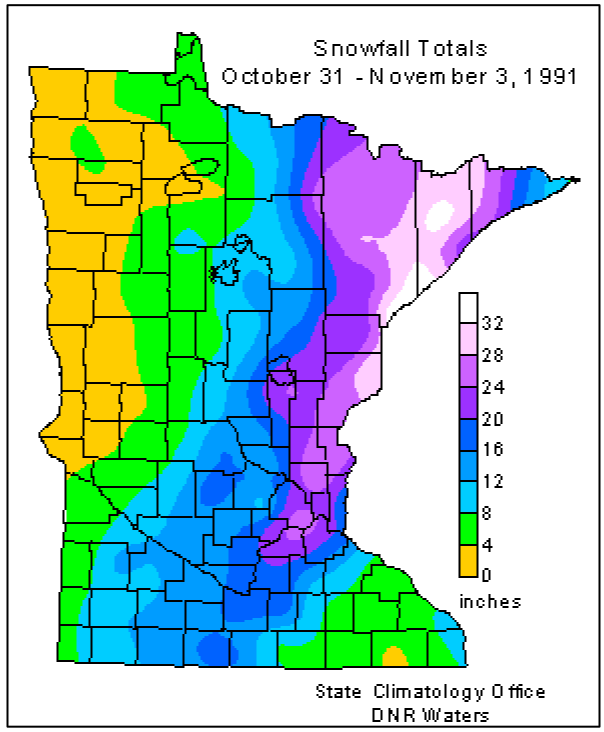
Although the snow during the first two days of the storm was very heavy, it fell in light winds as a cold air mass remained in place over the region. The final wave of snow, however, was associated with a powerful and intensifying low pressure system, and produced a slight warm-up, followed by strengthening winds and rapidly falling temperatures. The large geographical reach of this storm system overwhelmed Minnesota's road networks, and many state highways and local roads became impassible and had to be closed. Thousands of travelers hoping to get into or out of Minnesota we forced to remain in place into the following work week.

Halloween Blizzard, October 31 – November 2, 1991.

A low pressure system dove into southern Texas from eastern Colorado, picked up copious moisture from the Gulf of Mexico, and then proceeded on a north-northeast path, nearly following the central portion of the Mississippi River, before passing through Wisconsin and out over Lake Superior. This scenario and trajectory produced a historic period of heavy snow in the

Twin Cities and much of eastern Minnesota, followed by intense winds and plummeting temperatures.

The snow began around noon in the Twin Cities and intensified throughout the day. Five to 10 inches had already fallen by the end of the day, and intense snowfall continued throughout the overnight period. By daybreak on November 1st, most of the Twin Cities area already had well over a foot of snow on the ground, with heavy snow still falling. Many areas experienced a decrease in snowfall intensity beginning in the late morning, but snow nevertheless continued to accumulate at a rate of an inch every 2-3 hours throughout the afternoon and into the evening.



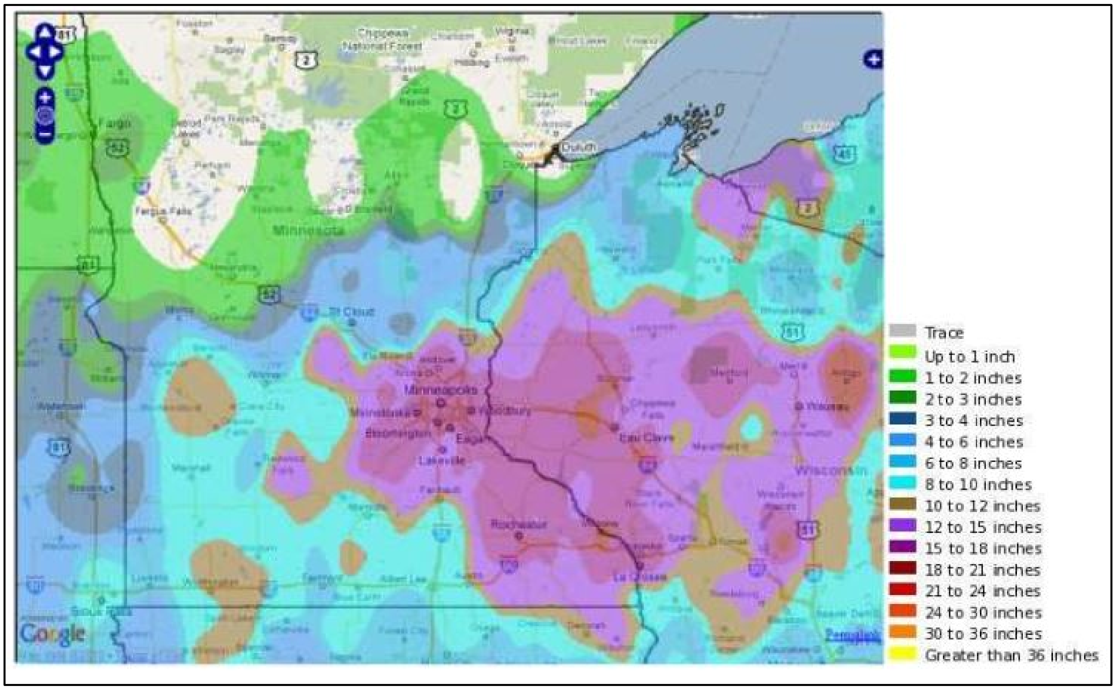
Snowfall totals from Halloween Blizzard. Courtesy of Minnesota DNR State Climatology Office

Winds had picked up during the morning also, and increased throughout the day, with sustained speeds between 20 and 30 mph with many gusts above 40 mph in the Twin Cities. By mid-evening, another band of heavy snow spread across the area, as winds reached peak speeds of 25-40 mph with gusts as high as 50 mph. Whiteout conditions permeated the entirety of Hennepin County during this period.

Snow continued at a lighter pace into the 2nd and even the 3rd of November, but the vast majority of of 25-30" totals fell on October 31st and November 1st.

The storm prompted school closings on both Friday November 1, and Monday November 4th in some districts, as snow removal efforts were significantly behind schedule. The storm broke daily and all-time snowfall records in the Twin Cities, and in its aftermath, the earliest subzero temperatures on record were observed.

Dome Teflon Roof #3 Snowstorm and Blizzard, December 10-12, 2010.
A very potent winter storm developed over South Dakota and Nebraska on Friday, December 10th, then strengthened as it moved into Iowa through Saturday, December 11th. Moisture surged into the Upper Mississippi River Valley ahead of the system on Friday, and precipitation pushed into the region during the overnight hours. Both coverage and intensity increased during the day on Saturday, and winds increased to 25-40 mph with higher gusts by afternoon.



Snowfall totals from December 10-12, 2010 storm. Courtesy of NWS Chanhassen

Very heavy snow accompanied this system, with widespread totals between 12 and 24 inches. The Twin Cities recorded 17.1 inches, making it the fifth largest snowstorm on record, and the largest in December. For the third time in 30 years, the excessive snow load ripped and then collapsed the Teflon roof of the Metrodome.

4.3.11.8. Future trends/likelihood of occurrence

Research on the future of winter storms in Minnesota is lacking, but recent trends indicate a tendency towards increases in the size of the largest snowfall events. However, this increase is not yet statistically significant.

Climate change on one hand is causing a rapid warming of winter, and on another hand is putting more water vapor into the atmosphere. Therefore it is plausible that snowstorm intensity could increase, even as seasonal snowfall decreases. However, using data from the Twin cities and Minnesota, there is no evidence that seasonal snowfall is decreasing, even though significant winter warming is well underway. It is possible that the current trend of an increase in high-end snowfall events will continue.

Using the Twin Cities snowfall record from 1900-2015, a daily snowfall of just of six inches can be expected annually. The 10-year snowfall amount for a calendar day is just over 12 inches. These values can be analyzed for durations of up to 7 days and return periods of up to 100 years.

Snowfall amounts for a given event duration and return period, based on Twin Cities data from 1900-2015.

Return Period	Daily Snowfall	24-hour Snowfall	2-day	3-day	5-day	7-day
Annual	6.2"	7"	8.4"	9.8"	11.5"	13.3"
2-year	8"	9"	10.7"	12.6"	15.3"	17"
5-year	10"	11.3"	13.7"	16"	17.9	21.6"
10-year	12.2"	13.9"	16"	17"	22.6"	26.7"
20-year	14.9"	16.9"	17.4"	21.1"	28.4"	35.9"
50-year	17.2"	19.4"	20"	27.8"	37.4"	39.7"
100-year	18.3"	20.7"	26.7"	34.2"	39.1"	40"

Using the same data somewhat differently, we can assess the expected frequency of common daily snowfall amounts.

Snowfall *equal or exceeding:*	Frequency
1"	15-18 per year
2"	8-9 per year
4 "	3 per year
6 "	1-2 per year
8"	Once per year or two
12"	Once per 6 years
16"	Once per 19 years

Frequency with which a daily snowfall total at a point in Hennepin County will equal or exceed a given amount.

4.3.11.9. Indications and Forecasting

The Twin Cities/Chanhassen forecast office of the National Weather Service is the official forecasting authority for major winter weather events affecting Hennepin County. High-intensity winter storms are usually well anticipated by the numerical weather prediction models, often up to a week in advance, and forecasters tend to have high awareness of potentially dangerous winter conditions two days or more before they develop.

Warning Products		***Remarks***
Blizzard Warning	Sustained wind or frequent gusts greater than or equal to 35 mph accompanied by falling and/or blowing snow, frequently reducing visibility to less than 1/4 mile for three hours or more.	*A major life safety hazard is ongoing or imminent. Danger is greatest for those traveling or caught outdoors. May be issued 2-4 times per year in open areas of far southern and western Minnesota. Very rare in Hennepin County; last one was November 1-2, 1991.*
Winter Storm Warning	Snow, ice, or sleet equaling or exceeding 6 inches in 12 hours and/or 8 inches in 24 hours, or a combination of snow, ice, or sleet and blowing snow with at least one of the precipitation elements meeting or exceeding warning criteria.	*This product spans a large range, from heavy snow events with little or no wind, to major wind-driven events that produce near-blizzard conditions. Typically 2-4 issued for Hennepin County per winter.*
Watch Product Name		
Blizzard Watch	Conditions are favorable for (i.e., there is the potential for) a blizzard event to meet or exceed Blizzard Warning criteria	*Potential exists for major life safety hazard, but uncertainties preclude a Warning at this time. Also very rare in Hennepin County, with no known instances in last 25years.*
Winter Storm Watch	Conditions are favorable for a winter storm event as defined above, but not yet enough certainty to issue a Warning.	*As certainty about an event approaches, may be "upgraded" to a warning. Many become lower-standing Advisories, and about 1/10 Watches end up with no Warning or Advisory product.*
Advisory Product Name		
Winter Weather Advisory	Winter weather event having one or more hazards (i.e., snow, snow and blowing snow, snow and ice, snow and sleet, or snow, ice and sleet) meeting or exceeding locally defined 12 and/or 24 hour advisory criteria for at least one of the precipitation elements but remaining below warning criteria.	

In ideal situations, progression of NWS products used will include a Hazardous Weather Outlook, Winter Storm Watch, and then Winter Storm Warning. Advisories and High Wind Warning. In some cases, damaging and even deadly winds have arisen within Wind Advisories.

4.3.11.10. Critical Values & Thresholds

The baseline for a Winter Storm product (i.e Watch or Warning) is generally 6 inches in 12 hours or 8 inches in 24 hours. The baseline for an Advisory is generally 3 inches in 12 hours. However, NWS forecasters may issue Watches, Warnings and Advisories at lesser thresholds if other hazards or concerns warrant a different standard.

4.3.11.11. Preparedness

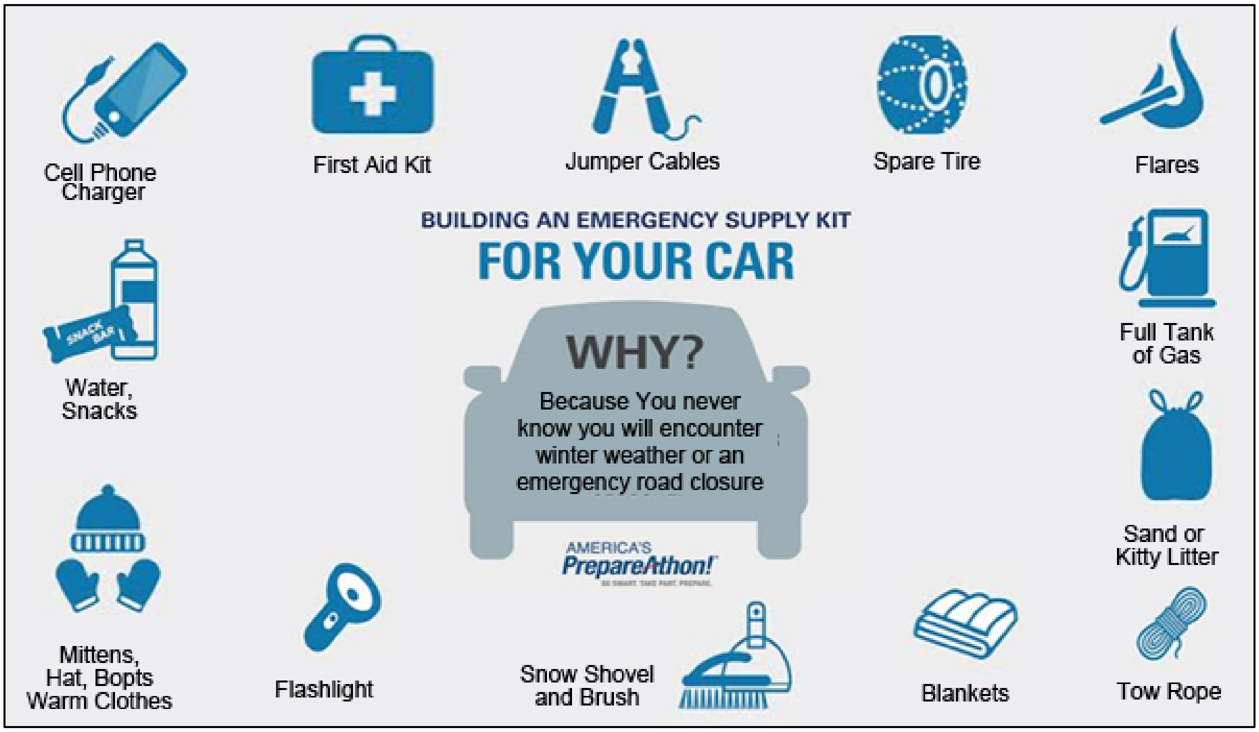
Before the storm strikes, homes, offices and vehicles should be stocked with needed supplies.

At home or work, primary concerns are primary concerns are loss of heat, power and telephone service, and a shortage of supplies in prolonged or especially severe and disruptive events. Essential supplies include:

- Flashlight and extra batteries
- Battery-powered NOAA Weather Radio and portable radio to receive emergency information
- Extra food and water such as dried fruit, nuts and granola bars, and other food requiring no cooking or refrigeration.
- Extra prescription medicine
- Baby items such as diapers and formula
- First-aid supplies
- Heating fuel
- Emergency heat source: properly ventilated fireplace, wood stove, or space heater
- Fire extinguisher, smoke alarm; test smoke alarms once a month to ensure they work properly
- Extra pet food and warm shelter for pets
- Back-up generator (optional) but never run a generator in an enclosed space
- Carbon monoxide detector
- Outside vents should be clear of leaves, and debris, and cleared of snow after the storm.

In vehicles, the supplies in **GRAPHIC 4.3.11A** are essential for winter storm survival.

GRAPHIC 4.3.11A Source: NWS Winter Storm Safety (http://www.nws.noaa.gov/om/winter/before.shtml)



If traveling on the road for a significant length of time, be aware of the weather forecast, especially if you will have long drives with large distances between towns. Stay "connected" via television, radio, NOAA Weather Radio, or social media. Major winter storms rarely occur without warning, although road travel can subject motorists to rapidly-changing, sometimes unexpected weather conditions. Thus, check forecasts throughout your route each day before your leave, and plan accordingly.

4.3.11.12. Mitigation

Education and Awareness Programs

- Vehicle fleet crews and others who spend substantial time on the road should be familiar with NWS warning products, jurisdictions, and be familiar with how to obtain pertinent information. All professional drivers should carry winter weather survival supplies.
- Homeowners and commercial properties should be aware of snow load safety and best practices for preventing roof damage. See FEMA document P-957, “Snow Load Safety Guide” (January 2013)
- Members of the general public should understand the risks posed by winter storms, and should review the information available at https://dps.mn.gov/divisions/hsem/weather-awareness-preparedness/Pages/winter-storms.aspx.

4.3.11.13. Recovery

Recovery from a major snow event can take days, or even weeks if it is complicated by a combination of cold weather, power outages, fallen trees, ice, or snow. In forested areas, logging activities may be significantly impacted, and fuel loads may exacerbate the potential for wildland fire. In addition to power outages, persistent wind loading on structures has at times caused gas line ruptures.

4.3.11.14. References

Minnesota DNR State Climatology Office, *75th Anniversary of the Armistice Day Blizzard*, http://www.dnr.state.mn.us/climate/journal/armistice_day_blizzard.html

Minnesota DNR State Climatology Office, *Tornado of March 31, 2014*, http://www.dnr.state.mn.us/climate/journal/tornadoes140331.html

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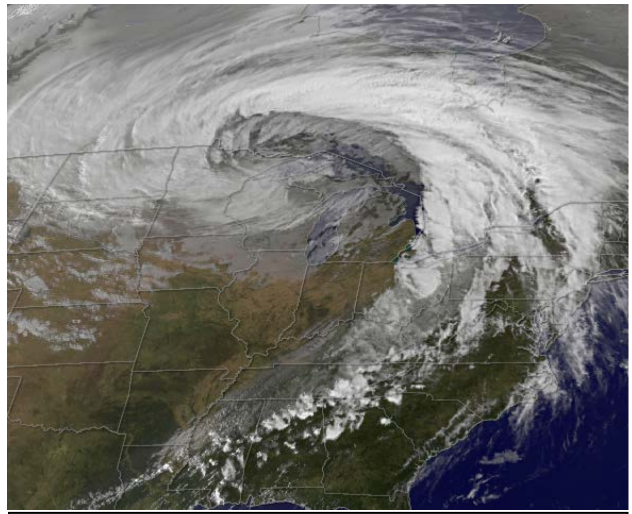
National Weather Service- La Crosse Forecast Office, *Armistice Day Storm - November 11, 1940*, http://www.weather.gov/arx/nov111940

National Weather Service-La Crosse Forecast Office, *Blizzard / Winter Storm of December 10-12, 2010*, http://www.weather.gov/arx/dec1110

Schwartz, Robert M., and Thomas W. Schmidlin. "Climatology of blizzards in the conterminous United States, 1959-2000." Journal of Climate 15.13 (2002): 1765-1772.

4.3.12.	Hazard Assessment: WINDS, NON-CONVECTIVE HIGH

4.3.12.1. Definition



Satellite image of the October 26, 2010 cyclone that set low pressure records in Minnesota and produced 24 hours of non-convective severe-threshold winds covering over 100,000 square miles.

Non-convective high winds are rare, long-lasting, sustained events that can pose significant life safety risks and produce widespread damage over a large area, while originating from sources unrelated to thunderstorms (i.e., not related to tornadoes or thunderstorm downbursts). In the Upper Midwest and the majority of the US, they form in association with intense and/or rapidly intensifying mid-latitude cyclones (low pressure systems). "Wake lows" developing behind thunderstorms have been observed to produce relatively prolonged bouts of non-convective strong winds in Minnesota--sometimes resulting in damage-- but these events are best considered within the spectrum of consequences and cascading effects resulting from derechos and other severe thunderstorms events.

The most common scenario in Minnesota, occurring 1-3 times per year on a statewide basis, is for a prolonged (multi-hour) period of sustained 30-45 mph winds, with frequent gusts to 60 mph, and isolated gusts as high as 70 mph. These events tend to result in sporadic minor structural damage, and occasionally cause isolated injuries or even deaths.

A more dangerous class of events occurs roughly once or twice per decade in Minnesota, and produces a pocket of enhanced wind speeds, often sustained above 45 mph for several hours, with gusts exceeding hurricane force. These events produce massive wind loadings that can result in significant infrastructural and property damage, and the most extreme among them yield death and injury rates that resemble those of tornado outbreaks.

Unfortunately, the meteorological differences between these two classes of events are quite subtle, and identifying the potential for the higher-impact extreme cases remains a forecasting challenge. In fact, every instance of them on record in the Upper Midwest has been under-forecast, in some cases significantly. Like *derechos*, there is no specific National Weather Service warning product for them. Most events in Minnesota have occurred during High Wind Warnings, within lower-priority Wind Advisories, and even during Blizzards Warnings. Those latter cases will be considered under *Blizzards* and will be discussed only briefly here.

Further complicating matters, no standardized database or method for cataloging non-convective extreme winds exists. Therefore, precise statistics on areal extent, duration, and total impact are lacking.

4.3.12.2. Range of magnitude

Maximum event (Hennepin): measured gust 89 mph at MSP on October 10, 1949
Maximum event (non-Hennepin): measured 100 mph at Rochester on October 10, 1949
Maximum duration: 36 hours, Wisconsin, October 26-27, 2010
Maximum sporadic wind damage footprint: 1000 mi long x 450 mi wide, November 10, 1998 and October 26-27, 2010
Maximum extreme wind damage footprint (MN): 400 mi long x 200 mi wide, October 10, 1949

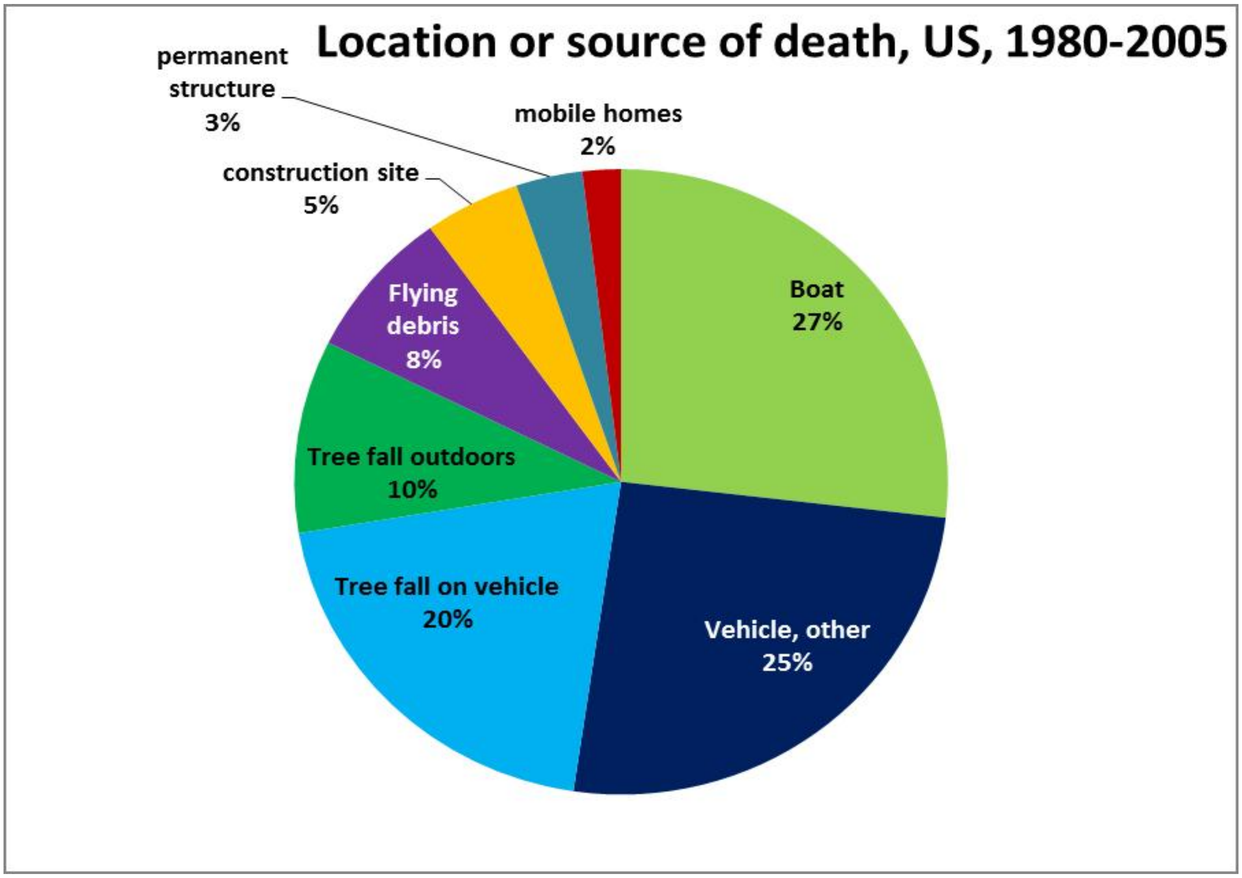
Summary of typical versus extreme non-convective wind events

Event Type	Frequency per decade	Maximum *sustained* winds (mph)	Maximum wind *gusts* (mph)	Damaging wind duration (hr)	Extreme wind duration (hr)	Footprint
High Wind	10-30	30-45	55-70	4-8	NA	Isolated minor structural damage covering an area the size of MN. Injuries/deaths in 5-10% of events
Extreme Wind	1-2	45+	75-100	6-24	3-6	Isolated minor structural damage covering several states. Significant infrastructural and property damage covering dozens of counties. Numerous injuries/deaths per event common.

4.3.12.3. Spectrum of Consequences

Non-convective winds killed nine Minnesotans between 1980 and 2005, with several other deaths possible between 2006 and 2014. Estimates suggest 20-40 additional deaths occurred between 1940 and 1979. Thus, with at least 30 deaths (and possibly as many as 55) since 1940, non-convective extreme winds clearly present a life safety risk on par with those of tornadoes and convective storm hazards.

Research has shown that non-convective wind fatalities are similar to derecho fatalities, in that the majority of them occur outdoors, in boats, or in vehicles. Only 5% of documented US non-convective wind deaths between 1980 and 2005 occurred within structures. By contrast, over 70% of tornado-related deaths occur within buildings or homes, illustrating that people are less likely to seek shelter during non-convective high winds than during tornadoes.



Sources and locations of US non-convective wind fatalities, modified from Ashley and Black 2008 (see references)

Unlike derechos, the peak frequencies of non-convective extreme winds occur during the mid-spring and especially mid-fall transition seasons. This timing minimizes the number of outdoor recreational activities, and reduces the potential exposure to wind-related hazards. The notable exceptions are 1) Minnesota's fishing opener, typically during the first half of May, at the end of the spring risk period, and 2) Minnesota's hunting seasons, which span the heart of the peak risk in October and November.

Boaters face substantial risks during non-convective high wind events. The reduced friction of open water often increases wind speeds and wave heights, and threatens to capsize boats. Once overturned or submerged, a boat's occupants will be subject to the seasonally-cold water, which poses serious risks for hypothermia and eventual drowning. Given the harsh conditions, rescue operations can be difficult, if not impossible. Several of the known deaths during the Armistice Day storm of 1940 were from skiffs that capsized in the 40-60 mph winds, hours before snow began to fall.

The prolonged nature of non-convective high wind events means that hunters and others spending time outdoors face extended risk exposure from falling trees. In urban or built-up areas, falling trees and power lines are the most typical sources of risk. During extreme events, urban inhabitants can be injured or killed by flying debris. In rural areas, outbuildings are often damaged, and barns frequently collapse.

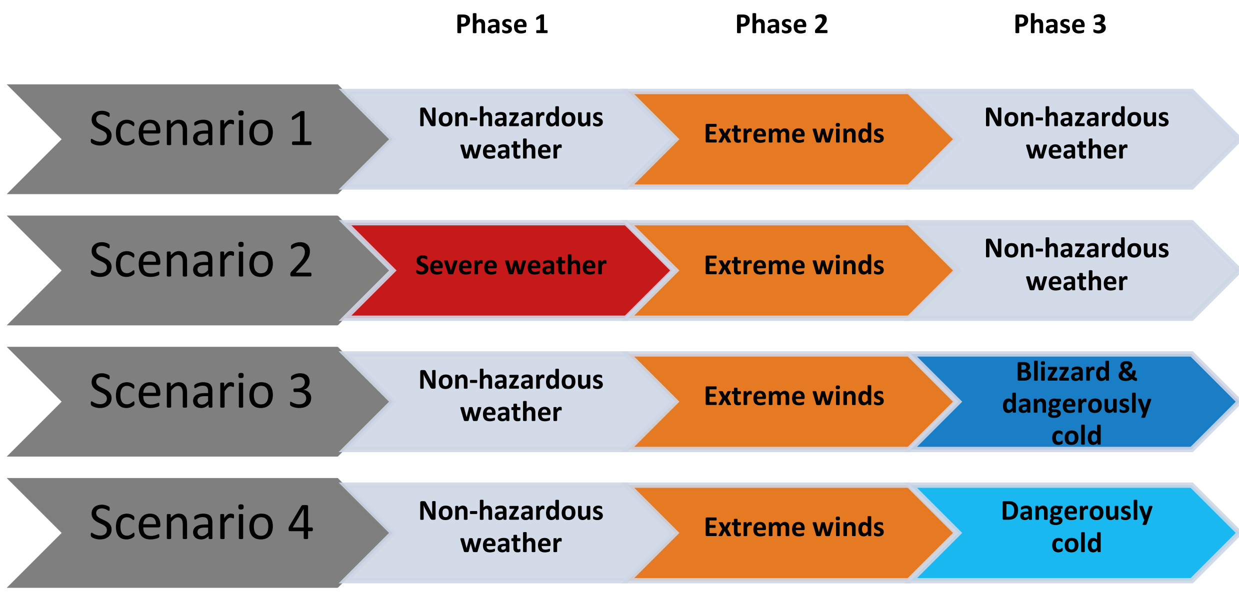
Occupants of cars and trucks also are vulnerable to being hit by falling trees and utility poles. Further, high profile vehicles such as semi-trailer trucks, buses, and sport utility vehicles are frequently blown over during sustained non-convective wind events.

Though they only make up 5% of the 1980-2005 deaths shown above, construction sites may make larger proportional contributions during periods of high economic growth, when the number of large projects multiplies. Workers have been and can be blown from ledges or scaffolding, and bombarded by loose materials.

Because they are so rare, the Twin Cities area has not experienced the consequences of a major non-convective wind event in several decades. Examination of the event in 1949, combined with what is known about derechos, suggests that a current-era repeat would be catastrophic. The total population exposed—outdoors, on the streets, in traffic—would likely be several times larger than in 1949. Power disruptions would cover the entire metropolitan area, and thousands of roads and street segments would be blocked by fallen trees, wires, and utility poles. The breadth of an extreme system, acting on our complex and dense concentration of overhead distribution feeders, would necessitate a massive temporary workforce in order to restore service after an event. Outages would likely last days, which could be particularly dangerous if winter conditions followed the high winds.

4.3.12.4. Potential for Cascading Effects

Non-convective high winds can occupy a large portion of any strong extratropical cyclone, and as a result can follow, precede, or be accompanied by a wide range of weather conditions. The parent intense low pressure systems frequently produce severe thunderstorms and tornadoes in areas that are later affected by the non-convective high or extreme winds. In some cases, the dangerous winds stretch far northwestward, into the portion of the cyclone where heavy snow is falling or has fallen. In these situations, severe blizzard conditions develop, and the winds function as one of many mutually-enhancing hazards.



The four generalized scenarios in which non-convective extreme winds most frequently occur in the Upper Midwest. It should be noted that a single system may produce different scenarios at different locations. The Armistice Day storm 1940 generated each of the four scenarios listed.

Considering that thunderstorm hazards tend to be distributed in the southeast quadrant of a cyclone, that blizzards tend to occupy the northwestern quadrant, and that any system capable of both will tend to move northeastward through the region, it is unlikely that any given location will experience severe thunderstorms, non-convective extreme winds, and blizzard conditions from the same system. However, a powerful system on November 11, 1911 did just that, producing killer tornadoes in Iowa, Wisconsin, Illinois, and Missouri, followed by record-setting temperature drops of 60-80 degrees in 6-10 hours with blizzard conditions and wind gusts as high as 75 mph. This event is a true singularity in the central US, in that nothing else like it has ever been recorded.

Perhaps the most common scenario for any one location in the Upper Midwest is that the extreme winds follow a period of inclement but otherwise non-hazardous weather, and are followed by a return to non-hazardous weather as well.

The scenario a given event follows is determined by both relative position with respect to the center of low pressure, and the depth of cold and/or warm air and moisture available to the system as it moves through the region. Those factors, in turn, influence the likelihood of cascading effects. In Scenario 1, the primary impacts are damage and power outages, and weather conditions in the storm's wake generally will not further escalate the situation. In all other scenarios, there is some potential for combinations of the following cascading effects.

Severe weather – Virtually all known non-convective extreme wind-producing systems in the Upper Midwest have also produced severe weather hazards somewhere within the storm's warm sector, which is in its southeast quadrant. Incidentally, concentrations of a system's most extreme non-convective winds typically follow the cold front into the southeast quadrant as well. Thus, if a sufficiently intense system produces tornadoes or straight-line winds (both of which can form in the high-shear environments of these systems if enough instability is present), some of the areas affected will be at risk for non-convective high or extreme winds, generally beginning 6-24 hours after the severe weather. Any debris generated by the severe weather will have the potential to become airborne and further scattered by the non-convective winds, prolonging the hazard exposure by hours. Moreover, the sustained wind loadings will further weaken or damage already-compromised structures, causing the potential for further collapse. The winds will also threaten to blow down trees and power structures previously spared. Lastly, these intense non-convective winds will add a layer of danger to ongoing search and rescue operations.

Blizzard – Although the very strongest winds tend to wrap into what had been the warm sector and are often removed from the area of heavy snow, the broad area of strong and even dangerous winds can reach back into areas experiencing (or previously experiencing) winter weather conditions. In these cases, the wind hazards are compounded by falling temperatures, reduced visibilities, and slippery or obstructed roads. Winds combined with heavy snowfall can knock down trees, power lines and power poles, blocking streets and cutting some residents off from their communities.

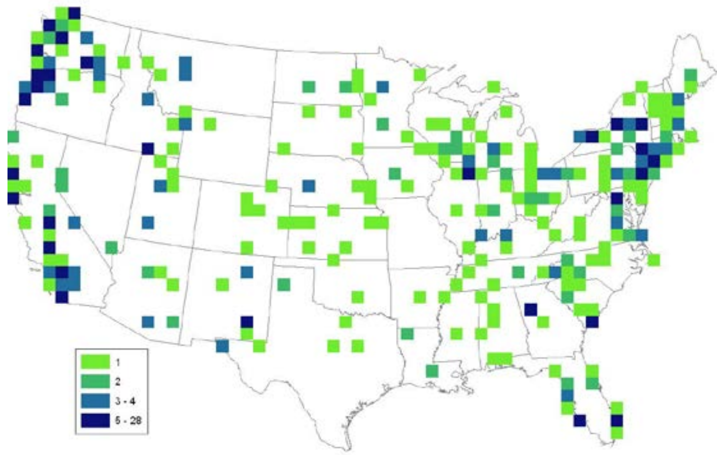
Cold – Even areas that do not experience blizzard conditions may see rapid temperature drops behind the cold front. Because these events usually occur during the transition seasons, the extent and depth of the cold air tend to be minimized. However, temperatures can fall near or below zero, and wind chill temperatures can fall to -25 or lower. The cold weather risks are greatest in areas that had lost power or utility service from extreme winds, as frostbite and hypothermia become serious concerns.

Flash Flooding – Most of the systems capable of extreme winds move quickly enough that precipitation amounts are kept under 2 inches. However, there have been instances of prolonged heavy rainfall and at least minor flooding, raising the possibility of a joint flood/non-convective wind disaster at some point in the future, though none have been recorded in Minnesota. The force of moving water combined with sustained strong winds would easily overwhelm stranded vehicles, and would significantly hamper rescue operations.

Wildland Fires – The swaths of trees toppled by non-convective high winds can increase fuel loads on forests, and escalating the risk of wildland fire. Additionally, although most non-convective wind systems produce some precipitation, many of the extreme winds come through "dry," and even in fair conditions. If the system passes through during a drought or other condition with unusually dry vegetation, the winds could easily enhance wildfire risk. Any existing fires would have the potential to spread rapidly and uncontrollably.

4.3.12.5. Geographic Scope of Hazard

A typical extreme wind-producing non-convective event may affect well over 100,000 square miles with wind damage, and may produce extreme impacts over tens of thousands of square miles. The total footprint may resemble those of derechos but the time signature is very different because non-convective events often affect large areas simultaneously and for much longer durations than convective weather systems.



Number of non-convective high wind fatalities in the lower 48 United States during the period 1980-2005. Source: http://earthzine.org/2011/06/04/death-from-a-clear-blue-sky-extreme-non-convective-high-winds/ (modified from Ashley and Black 2008)

Non-convective extreme winds have been recorded in every state, but their impacts are greatest in heavily populated areas, even though their frequencies and magnitudes may be greatest on the open Plains of the central US. The highest death rates per unit area are found in the northeastern US, between Maryland and New York state, where “nor’easters” can expose large, dense populations to hurricane-force (or greater) winds, and also along the Pacific coast. Death rates in these regions are 10 times higher than in Minnesota and the Upper Midwest, because of higher frequencies of intense low pressure systems, the complex topography found between the mountains and coasts induce wind-enhancing terrain effects, and the much greater population concentrations.

Within the Midwest, Minnesota appears to lie on the northwestern side of a risk corridor, which maximizes near Chicago.

4.3.12.6. Chronologic patterns (seasons, cycles, rhythm)

Non-convective extreme winds associated with strong low pressure areas are most common during the fall and spring transition seasons, when the polar jet stream’s mean track is near the Upper Midwest and when continental temperature gradients are strong. Although strong cyclone development is more common in spring than in fall, the conditions favoring explosive intensification are more common during autumn, and thus, October and November have by far the highest frequency for non-convective extreme winds.

4.3.12.7. Historical data/previous occurrence

The record of non-convective extreme wind events in Minnesota is incomplete, owing to the lack of adequate instrumentation, documentation and categorization. Knowing the true frequency of extreme winds in Minnesota would help estimate the likely recurrence of impacts on the modern landscape and population. The following events are those known to have produced significant non-convective wind impacts in Minnesota and the surrounding region.

The Armistice Day storm of November 11, 1940

Is best remembered as high-impact, high-mortality blizzard, but the extreme winds *prior* to the snow were responsible for much of the cascading disaster that followed. Extreme non-convective winds capsized skiffs used by hunters in southern Minnesota, and produced impossible navigation on the Mississippi River, which forced at least 12 hunters to shelter on islands, where they ultimately froze to death. The winds wrecked large vessels on Lakes Michigan and Superior, resulting in 59 fatalities. From Minnesota east into Michigan and Ohio, winds were sustained at 35 mph or greater for several hours, with many stations recording average speeds in excess of 50 mph. Gusts of 70-80 mph are believed to have been common throughout the region. The strongest winds were over Wisconsin, Illinois, and western Michigan, to the south and southeast of the intensifying low pressure center. The winds blew down utility poles, and cut power and communications to much of Minnesota, Wisconsin, Illinois, and Michigan, creating a dangerous situation as temperatures fell into the teens and single digits.

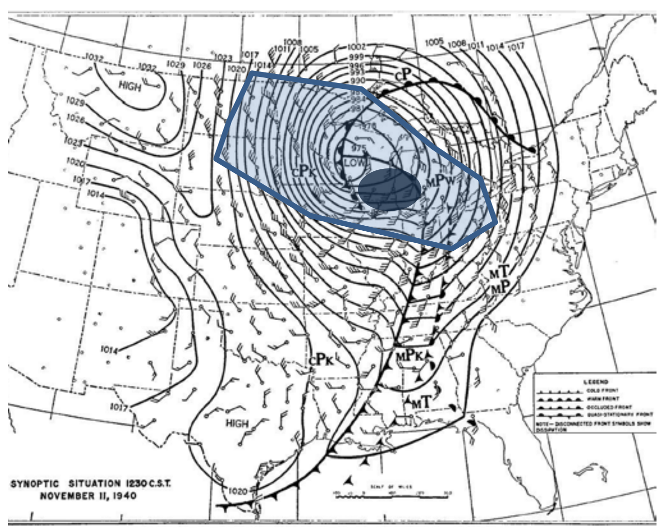


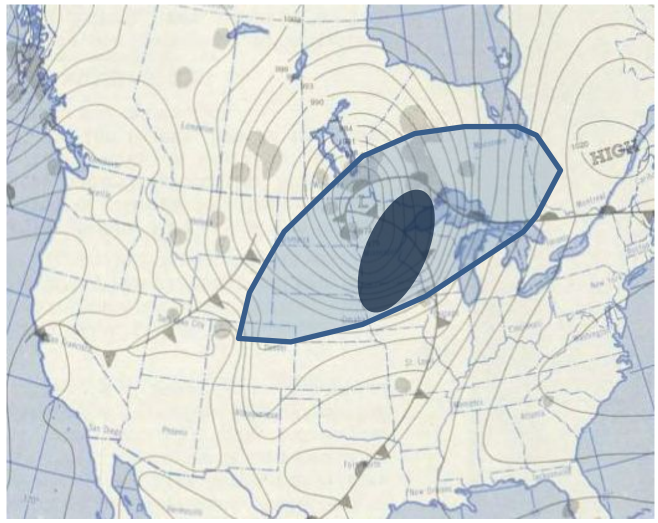
FIGURE 6.—Synoptic situation 1230 C. S. T., November 11, 1940.

Surface weather map, Nov 11, 1940. Shaded area represents region of wind impacts. Dark area represents hurricane-force wind gusts. Modified from La Crosse NWS.

The event produced all four extreme wind scenarios described previously in different parts of the region. Across much of Wisconsin, Lake Michigan and Lower Michigan, the dangerous, prolonged winds of 40-60 mph (gusting up to 80 mph) were the only significant hazard posed by the storm. Over Iowa and Illinois, tornadoes and severe thunderstorms swept through the area during the morning, and then non-convective sustained winds of 25-45 mph (gusting 55-70 mph) blew for 8-12 hours following the passage of the strong cold front. Over western Iowa, much of Minnesota, northwestern Wisconsin and the eastern Dakotas, non-hazardous weather gave way to strong winds gusting up to 70 mph, severe blizzard conditions, and dramatically falling temperatures; these conditions stranded and killed at least two dozen motorists. Lastly, the central and western Dakotas had wind gusts to 65 mph, little or no snowfall, but dangerously cold temperatures.

On *October 10, 1949*

The most severe non-convective wind event on record in Minnesota struck the majority of the state and produced over 75,000 square miles of derecho-level damage. Minneapolis recorded seven straight hours of sustained winds above 40 mph, three hours of sustained winds above 50 mph, and two hours of gusts exceeding 75 mph, including a maximum gust of 89 mph. In Rochester, a 100 mph wind gust was recorded. Boat works facilities were demolished on Lake Minnetonka, as well as numerous other Minnesota lakes; docks were destroyed and sailboats were piled onto the shores of Minneapolis lakes; windows were blown out of homes, storefronts, and office buildings; and many brick buildings partially collapsed. In downtown Minneapolis, large signboards were twisted, the 65-foot chimney of the Sheridan Building fell onto and severely injured several people, and workers on upper floors of the Foshay Tower fell ill from motion sickness due to the extreme swaying of the building. The winds inflicted destruction or severe damage upon barns, windmills, water towers, and grain elevators throughout rural Minnesota. The event claimed 27 lives region-wide (four in MN), and severely injured hundreds (at least 100 in MN). Many of the casualties were caused by blunt trauma from flying or falling objects, and lacerations from flying glass. Northern States Power counted approximately 4800 broken lines and 600 broken poles in southern Minnesota alone. An additional 48 broken poles were counted in the Fergus Falls area. In some areas, outages lasted into early November. Losses exceeded $100 million USD (2014) at a time when there was far less infrastructure and property than there is today.



Surface weather map, Oct 10 1940. Shaded area represents region of wind impacts. Dark area represents hurricane-force wind gusts Modified from Daily Weather Maps

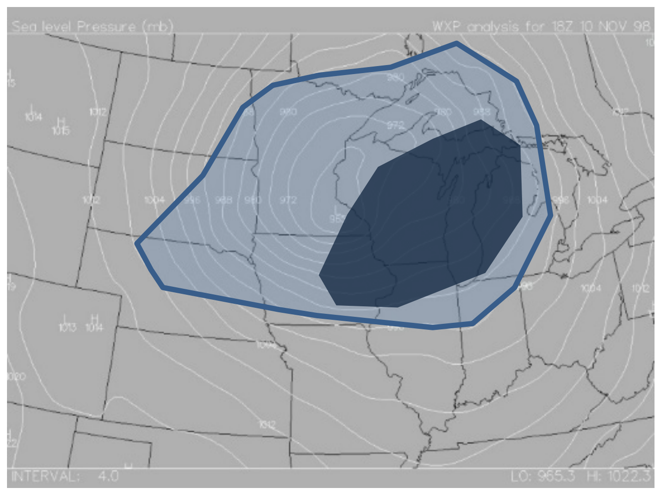
This storm system produce a band of occasionally heavy rain that in some cases fell into the howling winds, producing visibilities near zero at times. The rain itself otherwise had a marginal impact (no significant flooding, no damage), and although severe weather was reported well to the south of the region, no other significant hazards preceded or followed the extraordinary winds in Minnesota and the Upper Midwest.

On November 10, 1998

An explosively intensifying low pressure system tracked from Kansas to western Lake Superior, producing a wide array of dangerous weather conditions, punctuated by a deadly, long-lasting bout of non-convective extreme winds. The storm set the statewide low-pressure record (at the time), with 962.7 millibars registered at both Albert Lea and Austin.

Although most of Minnesota had widespread 30-50 mph winds, with gusts up to 75 mph, the most devastating winds stretched from central Iowa, through the majority of Wisconsin, and into Upper and western Michigan. These areas experienced up to 18 hours of sustained 35-50 mph winds with frequent gusts of 65-75 mph, and many gusts exceeding 85 mph, including a 93 mph gust recorded at the La Crosse NWS office. Wind gusts exceeded 85 mph over far southeastern Minnesota.

The winds resulted in 10 deaths, 34 serious injuries, and at least $50 million USD (2014) in damages. Wisconsin was hardest hit, but impacts were severe in Minnesota, where a school bus was blown of the road, and hunters in the Paul Bunyan State Forest were stranded in heavy snow and high winds because dozens of fallen trees blocked all possible exits. Near Foxhome in northwestern MN, 27 consecutive power poles were snapped.



Surface weather map, 12:00 PM CST, Nov 10 1998. Shaded area represents region of wind impacts. Dark area represents hurricane-force wind gusts. Base map generated from Plymouth State Weather Center.

The Milwaukee and Green Bay, WI National Weather Service offices collected detailed information on the storm. Some of the worst impacts (all Wisconsin) included:

- Green Lake Co: barn leveled on outskirts of Berlin. Shingles ripped off business in Green Lake. Light poles bent by wind in Berlin.
- Sauk Co: Shed demolished in Baraboo area. Tree fell on trailer near Lake Delton. Many trees and power lines downed in eastern part of county near Wisconsin River, causing 1000 outages.
- Columbia Co: 50-year-old woman killed when blown into Wisconsin River, where extreme winds created powerful undercurrent. Semi-truck tipped over on I-94. Columbus, a home's brick chimney damaged, and roof of balcony ripped off.
- Iowa Co: elderly man near Cobb suffered head injury after being knocked down by a gust of wind. Semi-truck driver injured when vehicle flipped over by wind gust on Highway 80, just north of Stephens. Five other semi roll-overs in county. Apartment building and hotel in

Dodgeville sustained roof damage. New home under construction demolished. Barn collapsed in rural Hollendale. New building destroyed near Spring Green.

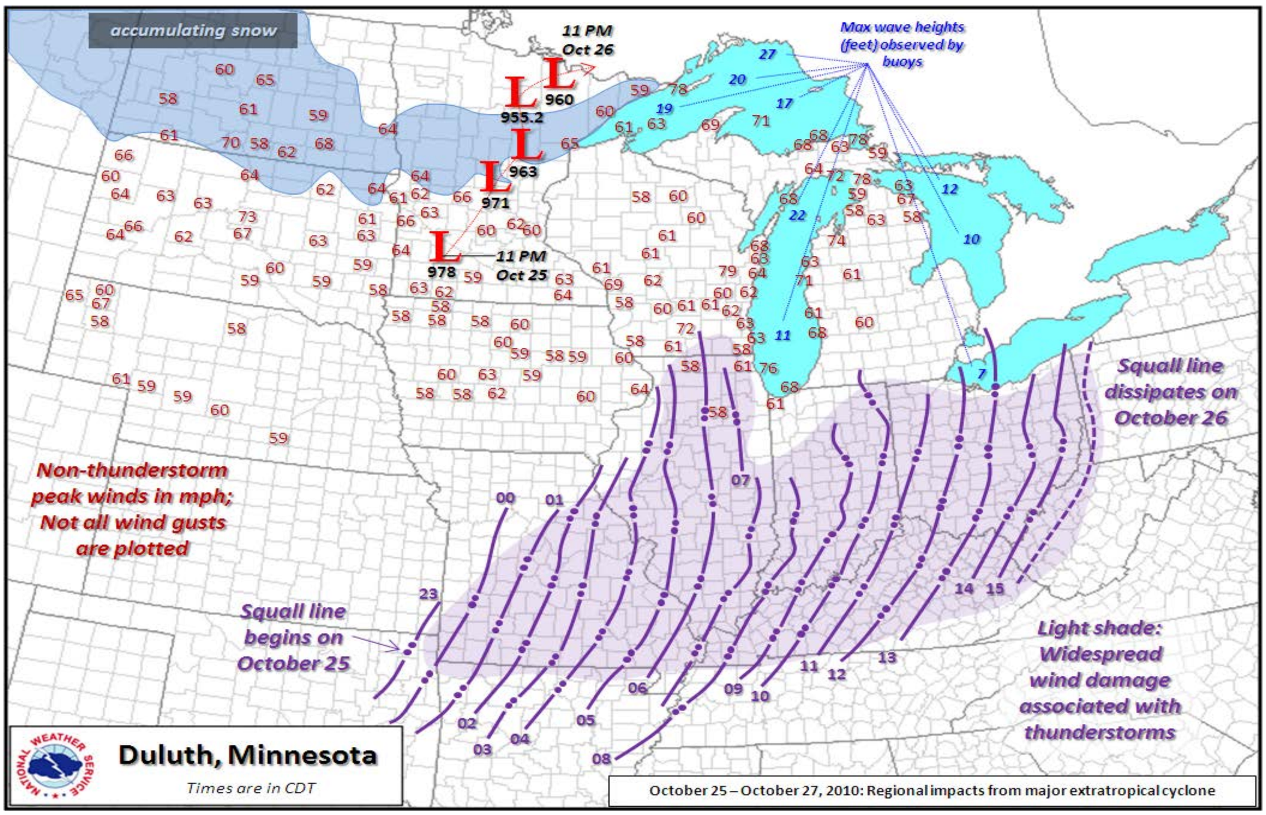
- Dane Co: 87 year-old man died after car blown into him on north side of Madison. Capitol Square business had window blown in. Several businesses in Mt. Horeb sustained wind damage. Roof torn off multi-unit apartment building in Manona, and 4 other nearby buildings also damaged. Two businesses in Stoughton damaged. 12 semi-trucks flipped over in 10-min period on I-90/94, and several more on US18/151 and Hwy 51. Several barns in county damaged. Moored boats on Lake Kegonsa were pushed into each other, resulting in damage.
- Lafayette Co: Large portion of Darlington High School roof ripped off. Elsewhere in county, 5 farm buildings destroyed, 15 more damaged. Five homes in county sustained damage due to fallen trees, and 1 business suffered structural damage. Several county roads blocked by tree debris.
- Green Co: Semi roll-overs reported on US 11/81, and Hwy 81 in town of Monroe. Airplane flipped over at Brodhead airport. Silo roof blown off on County M. Damage inflicted on county salt sheds in New Glarus and Brodhead. Approx. 5000 customers without power at one time.
- Rock Co: Beloit, 25 large trees knocked down, damaging several homes. 1/3 of Janesville Parker High School roof torn off. Evansville, two businesses with blown-in windows, and siding peeled off on 5 other buildings. Edgerton, 2 homes sustained damage from fallen trees, 5 businesses lost siding. Approx. 14,000 county electrical customers without power.
- Fond du Lac Co: City of Fond du Lac, sheet metal and siding on a church steeple peeled off by the wind, over 100 homes damaged. Eden, shed blown away. Two semis flipped by wind on Hwy 41, and cars pushed or blown into ditch. Oakfield, roof of pig barn ripped off. 2800 county electrical customers without power.
- Sheboygan Co: woman in Sheboygan injured by flying glass debris after window blown out of a business. Two other city businesses suffered roof/sheet metal damage. Barn near Plymouth leveled. Semi-truck tipped over on Hwy 23 west of Sunset Rd. Three homes in Sheboygan Falls damaged by felled trees.
- Dodge Co: scattered damage reported in all parts of county. Juneau, roof was ripped off business building. Three semi-trucks flipped over. Approx. 2000 county customers were without electrical power at one time. Multiple-vehicle accident near intersection of Hwy 151 and 16-60 due to vehicles being pushed sideways by gusts.
- Washington Co: Approx. 8000 customers lost electrical power. Two semi-trucks flipped over on Hwy 45, resulting in closure of road. County 911 center logged 54 call for damage assistance. Barn blown down on Hwy 28 near Kewaskum. Several schools closed early.
- Ozaukee Co: Siding ripped off several homes and telephone poles snapped in Port Washington. Belgium, about 1/4 of roof was torn off building under construction. Several schools closed early in Mequon and Thiensville.
- Jefferson Co: Ft. Atkinson woman injured after when blown into side of her home. Semi-truck driver injured when truck flipped over on I-94 near Hwy 26 interchange. Another semi overturned by a gust on US 18 near Hwy 89. At least 17 homes in county sustained damage from tree debris. Many acres of corn crop flattened. Barn blown across Hwy 106 east of Ft. Atkinson. Approx. 6000 customers lost electrical power. Concrete wall of new grocery store In Ft. Atkinson, blown down.

- Waukesha Co: Two women injured in Muskego when tree fell on car. New Berlin man injured after motorized garbage cart rolled over by a wind gust. Hwy J, Pewaukee, driver injured after tree fell on car. Approx. 15,000 customers lost electrical power. Semi-truck flipped over by gust on I-94 near Hwy 83 interchange. At least 3 barns in county were badly damaged. In both Muskego and Sussex, two new walls at school construction sites toppled. Construction site on Hwy 36 near Burlington badly damaged. Several boats damaged on county lakes due to large waves.
- Milwaukee Co: 87 year-old man fell face-first onto sidewalk when door he was opening blown from his hand; went into coma and died November 16. Southridge Mall, woman sustained head injury when blown over in parking lot. Hundreds of trees uprooted across county, damaging dozens of homes, apartments, and businesses. 20,000 customers lost electrical power. Traffic lights knocked out of service at 75 intersections. A train sustained damage from tree debris while moving through northern part of county. Significant damage to gates, ground equipment, and signs at General Mitchell Int'l Airport.
- Walworth Co: Semi-truck driver injured after vehicle flipped over on Hwy 11 near Racine Co. line. Roof damage to at least 6 businesses and nursing homes in county. Semi-truck rollover on I-43 near the Hwy X interchange resulted in spilled fuel that closed road. Several Whitewater buildings and a stadium damaged. Walls blown down at construction sites in East Troy and Elkhorn.
- Racine Co: Woman injured when traffic signal light blew onto her vehicle. Racine, woman injured when tree fell on home. Police officer injured by flying debris while out on a call. Construction wall blown down. Brown's Lake, shed destroyed. Several other homes and businesses sustained damage from trees.
- Kenosha Co: 16 year-old boy electrocuted in Bristol as he tried to escape after a wind gust toppled a live electrical line on his car. Near Salem on Hwy 50, small car partially airborne by wind gusts and blown into ditch. Semi-truck was flipped over on I-94.
- Brown Co: Kaukauna, several dozen homes evacuated when top of water tower holding 225,000 gallons blew off. Green Bay, Interstate 43 Tower Bridge closed because of multiple semi blow-overs.

The record-breaking extra-tropical cyclone October 25-27

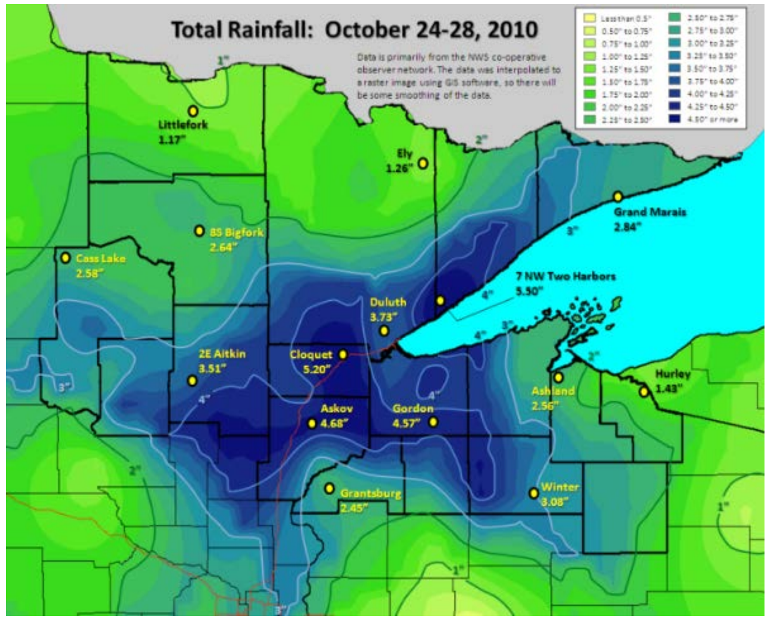
2010 brought a widespread severe weather event and serial derecho to the lower-Midwest, followed by a massive, 2-day non-convective high wind event that stretched from the Dakotas and Nebraska to Michigan. The sea-level pressure of 955.2 millibars at Bigfork, MN shattered the previous state record set by the November 10, 1998 storm system. The reading at Bigfork is also the lowest on record anywhere in the Central US, and is a mere 0.2 millibars from the record for contiguous US.

Despite the extraordinarily low pressure, the enormous area occupied by non-convective high winds, and the unusually long duration, this event lacked the wind severity of those in 1949 and 1998. 60 mph gusts were observed at the majority of stations in the storm's 8-state footprint, but not a single station recorded an 80 mph gust. The winds produced nearly 500,000 power outages (at one point or another), toppled thousands of trees and power lines, but produced fewer casualties (2 fatalities and 8 injuries), and a lesser degree of property and infrastructural damage than the other systems. This result is not well understood, because wind speed and impacts tend to be highly and strongly correlated with the strength of the cyclone, as represented by its lowest sea-level pressure. It is possible that this event, for a currently unknown reason, failed to produce or incorporate the dynamical and mesoscale features that typically produce extreme winds in high-intensity systems.



Locations of non-convective 58 mph or greater gusts, cyclone center, and other hazards. Courtesy NWS Duluth.

The October 2010 event was also unusual because it produced pockets of excessive rainfall. Typically, strong regional winds aloft with these systems prevent thunderstorms from training, and ensure that precipitation is not prolonged. Thus, the highest precipitation total is usually kept below 2 inches. In this case however, numerous clusters of thunderstorms formed just east of the advancing low center, producing widespread heavy rainfall. As the cyclone reached peak intensity, its forward motion slowed dramatically, and heavy stratiform precipitation (eventually changing to heavy snow) impacted many of the same areas that received repetitive thunderstorms. Portions of northeast Minnesota received over four inches of precipitation, with isolated reports of over 5 inches, resulting flooded intersections, submerged roads, and minor damage to businesses and residences. The locations receiving the heaviest rainfall were in the same position with respect to the cyclone center as areas that often receive the most intense non-convective winds; fortunately, however, this storm did not produce such winds, and there were few or no compound flooding/extreme wind effects.



Rainfall associated with October 25-27 non-convective high wind event. Courtesv NWS Duluth.

4.3.12.8. Future trends/likelihood of occurrence

Non-convective high winds are relatively rare, occurring, on average, fewer than three times per year in Minnesota. *Extreme* events, are even rarer, and only affect some part of the state approximately once or twice per decade. Open areas of the state in the west and south are more conducive to non-convective high winds than other areas, but extreme non-convective winds do not appear to follow that pattern. If anything, extreme winds, and especially the impacts of them, are slightly more common in the hilly and tree-filled eastern parts of the state than on the open prairies.

The frequency of non-convective extreme wind in Minnesota is directly tied to the frequency of intense mid-latitude or extratropical cyclones. Unfortunately, the physical link between explosive cyclogenesis (the process that leads to intense low pressure systems) and human-caused climate change, is not well understood, so research into the future of these systems has been inconclusive, with results depicting all possible scenarios.

Consultation of all available research suggests that extreme non-convective winds have a frequency similar to high-end tornado events, with recurrence intervals on the order of multiple decade.

4.3.12.9. Indications and Forecasting

Forecasting authority for non-convective high wind events rests with local National Weather Service forecast offices. High-intensity mid-latitude cyclones are usually well anticipated by the numerical weather prediction models. As a result, forecasters tend to have high awareness of potentially strong winds 2 days or more before they develop. In ideal situations, progression of NWS products used will include a Hazardous Weather Outlook, High Wind Watch, and High Wind Warning. In some cases, damaging and even deadly winds have arisen within Wind Advisories.

Despite high awareness of strong regional wind potential, the majority of non-convective high wind events in the region, and *all* extreme events, have been under-forecast. As a result, the impacts have come as surprises. An after-action report from the disastrous 1949 event concluded that forecasters had "little evidence by which the severity might have been forecast." Although forecasting techniques have improved dramatically since that time, underestimation is still a concern. The November 10, 1998 event forecast products made no mention of winds exceeding 65 mph, yet there were dozens of separate instances of winds exceeding 80 mph throughout the region. Even the lower-impact, October 2010 event had dozens of gusts exceeding the maximum thresholds named in forecast products. The forecasting challenges arise from a combination of low event frequency, low priority (when compared with other hazards), and limited understanding of the latest research.

Recently, mechanisms contributing to cyclone-related, non-convective extreme winds have become better understood. Events with extreme winds share the following commonalities:

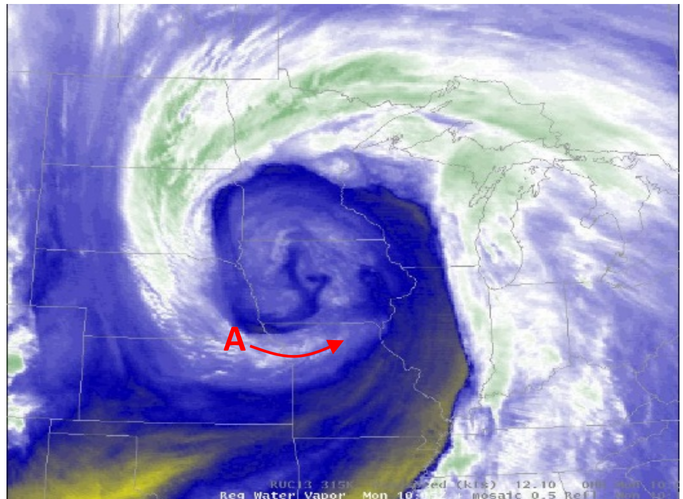
Intense cyclone. The strongest 5% of cyclones in the Upper Midwest have minimum sea-level pressure of 980 millibars or lower and produce strong regional winds. Both the likelihood and coverage of high and extreme winds increase as the minimum pressure drops, with 972 millibars serving as a threshold below which both are almost guaranteed.

→ *The first indicator that extreme winds are possible is the forecast of a sub-980 millibar cyclone within the region. The lower the forecast minimum pressure, the greater the potential for impacts. Potential can be ascertained several days in advance.*

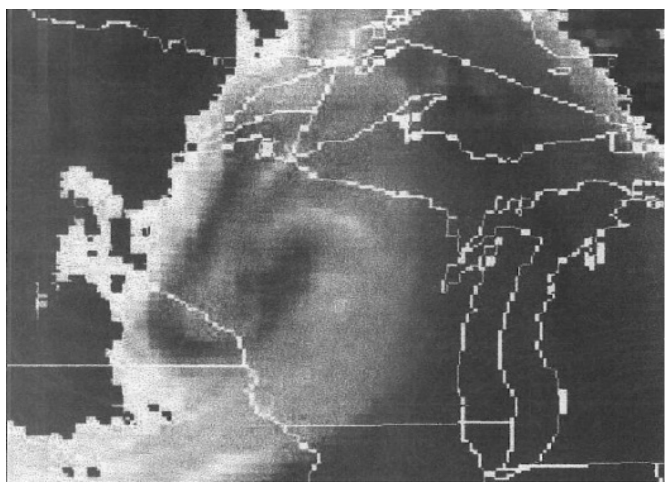
Cyclone passes north or northwest of area. Although non-convective strong and high winds can be distributed widely throughout the cool side of any intense cyclone, the most extreme winds tend to be found to the south of the center of low pressure, especially in cyclones whose minimum pressure is below 972 millibars. This is most likely within 300 miles of the cyclone, but distances vary depending on the circulation structure. For example, the October 1949 event had its maximum impact area 150-300 miles southeast of the low, versus 25-150 miles to the south of the low in the November 1998 event.

→ *The second indicator that extreme winds are possible is if the sub-980 millibar cyclone is forecast to pass northwest or north of the area. The nearer the cyclone (to the* *north/northwest), the greater the potential for impacts, especially if the minimum pressure is forecast below 972millibars. Potential can be ascertained 1-3 days in advance.*

Presence of a "sting jet" or "mesoscale dry hook." The most intense non-convective winds tend to form in the cool air circulation that wraps around and to the south of the cyclone, in association with one of two features. The first is the "sting jet," which is associated with the pointed end of the comma-shaped cloud formation that wraps around the low. It is so named because of its resemblance to a scorpion tail. Another feature is the "mesoscale dry hook," which is a sharp, reverse-J-shaped feature that forms in the tightly-rotating comma head, which is found, incidentally, north and west of the sting jet. The strongest winds are often found near the base of the hook. The two features often move closer to each other as a cyclone reaches maximum intensity. Both are associated with descending or drying air, often originating in the strong winds in the mid-troposphere or above. If the descending air makes it to the ground, extraordinarily strong surface winds can result. The science is not sufficiently evolved to determine exactly which events were sting jets, mesoscale dry hooks, or both. However, either one is an excellent indicator of extreme wind potential, when a surface cyclone is of sufficient intensity (indicator 1 above). It should be noted that these features may form in the absence of a strong cyclone, but their airflows will remain aloft and therefore will not pose serious threats.



Sting jet (A), in association with strong system on Mar 12, 2012. Courtesy University of Wisconsin CIMSS.



Mesoscale dry hook with November 10, 1998 cyclone. Source: Iacopelli and Knox 2001.

→ *The third indicator that extreme winds are possible is the formation of a sting jet or a mesoscale dry hook (or both), which can be detected on satellite products.*

TABLES 4.3.12A and 4.3.12B can be used as guides for anticipating non-convective wind impacts, based on pressure ranges, distance from the cyclone, and location relative to the cyclone.

TABLE 4.3.12A

High Winds	Nearest distance to cyclone center: > 500 mi		300-500 mi		< 300 mi	
Lowest Pressure (mb) >980	Isolated	Isolated	Isolated	Low	Low	Low
972-980	Low	Low	Low	Mod	Mod	Mod
<972	Low	Low	Mod	Mod	Hi	Hi
Does cyclone pass northwest or north of area?	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**

Likelihood and coverage of high wind impacts, given cyclone intensity, distance, and location.

TABLE 4.3.12B

Extreme Winds	Nearest distance to cyclone center: > 500 mi		300-500 mi		< 300 mi	
Lowest Pressure (mb) >980	Unlikely	Unlikely	Unlikely	Isolated	Isolated	Low
972-980	Isolated	Isolated	Low	Low	Low	Mod
<972	Isolated	Isolated	Low	Mod	Mod	Hi
Does cyclone pass northwest or north of area?	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**

Likelihood and coverage of extreme wind impacts, given cyclone intensity, distance, and location.

4.3.12.10. Critical Values & Thresholds

Because duration is such an important component of the wind loadings and total impacts, no firm thresholds have been determined for non-convective wind speeds. However, research has shown that some impacts emerge when gusts exceed 60 mph. When gusts exceed 75mph, impacts are often widespread, and casualties tend to increase dramatically.

4.3.12.11. Preparedness

If planning to be outdoors for a significant length of time, be aware of the weather forecast, especially if you will be well-removed from sturdy shelter. Stay "connected" via television, radio, NOAA Weather

Radio, or social media. Non-convective high wind events rarely occur without warning, although warning lead times may be comparatively limited during the evolution of an extreme wind episode. Because protracted and extensive electrical and communication disruptions may occur, set aside emergency water and food supplies, can openers, batteries, and flash lights.

4.3.12.12. Mitigation

Education and Awareness Programs

- Field construction crews, public works employees, and those who work or spend significant time outdoors should be educated about these risks.
- Members of the general public should understand the risks posed by non-convective wind events.
- Educating homeowners on the benefits of wind retrofits such as shutters and hurricane clips.
- Ensuring that school officials are aware of the best area of refuge in school buildings.
- Educating design professionals to include wind mitigation during building design.

Structural Mitigation Projects – Public Buildings & Critical Facilities

- Anchoring roof-mounted heating, ventilation, and air conditioner units
- Purchase backup generators
- Upgrading and maintaining existing lightning protection systems to prevent roof cover damage
- Converting traffic lights to mast arms.

Structural Mitigation Projects – Residential

- Reinforcing garage doors
- Inspecting and retrofitting roofs to adequate standards to provide wind resistance.
- Retrofitting with load-path connectors to strengthen the structural frames

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4.3.12.13. Recovery

Recovery from non-convective high winds can take weeks, and may be complicated by a combination of cold weather, power outages, fallen trees, ice, or snow. In forested areas, logging activities may be significantly impacted, and fuel loads may exacerbate the potential for wildland fire. In addition to power outages, persistent wind loading on structures has at times caused gas line ruptures.

4.3.12.14. References

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4.3.13.	Hazard Assessment: ICE STORMS

4.3.13.1. Definition

Ice storms are major winter weather events that produce accumulations of ice, either from rain falling in sub-freezing surface temperatures, or from heavy sleet.

Significant ice storm damage in southwestern Minnesota in April 2013. Courtesy MPR.

In Minnesota and Hennepin County, ice storms form most commonly ahead of a warm front, resulting in warm air being lifted over colder air in place, producing precipitation that is warm enough for rain but then freezes on contact with sub-freezing objects. When the front is associated with strong low pressure, the precipitation can be quite heavy, with rapid ice accumulations. With weaker systems or when the front is stationary, it may produce sustained light to moderate precipitation for many hours. Either situation can lead to ice-related impacts.

If the layer of freezing air near the surface is deep enough, the precipitation will fall as sleet instead of freezing rain. The granular nature of sleet generally makes it less of a damage and safety hazard than freezing rain, but sleet is nevertheless often a part of major ice storms.

4.3.13.2. Range of magnitude

Magnitude of ice accumulation is rarely measured, and most accounts are purely anecdotal. Severe ice storms in Minnesota have been reported to leave a glaze up to 3 inches thick.

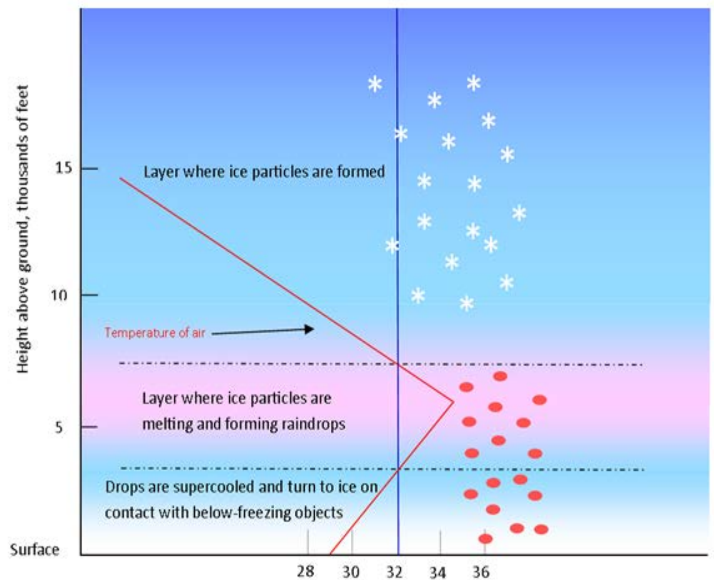
4.3.13.3. Spectrum of consequences

Heavy accumulations of ice can bring down trees, topple utility poles, and damage communications towers, disrupting power and communications for days, while utility companies make extensive repairs. Ice also damages roofs, gutters, and downspouts, and falling tree limbs often cause devastating secondary damages to structures and vehicles.

Even small ice accumulations can be extremely dangerous for motorists and pedestrians, and ice storms often result in increased accidents, falls, and injuries. The following categories represent the most common and severe consequences for ice storms:

Outdoor life safety hazards

If associated with a severe winter weather system, heavy snow, strong winds, falling temperatures and dangerous wind chills may follow the ice storm. Persons caught outside unprepared can face disorientation, frostbite, hypothermia, and death. 25% of winter storm casualties occur among those caught outside in the storm.



Temperature profiles associated with freezing rain. Source: Midwest Regional Climate Center.
http://mrcc.isws.illinois.edu/living_wx/icestorms/

Power/utilities

Ice storms can cause power outages from direct loading on electrical wires, and more commonly from indirect sources, for example when tree limbs become overloaded with ice and fall onto wires. Ice accumulations greater than ¼" can cause widespread power outages, and strong winds exacerbate this impact. The duration of service outages is typically related to the complexity of the outage pattern, along with the ability of crews to get to repair sites. Thus, prolonged ice storms with strong winds are associated with higher outage numbers and longer service delays.

Structural damage

Ice storms can damage roofs at residences, and at larger commercial facilities as well. Large roof spans lacking consistent support are especially vulnerable. Secondary damage from falling ice-coated tree limbs is especially common. These falling limbs are often significantly heavier because of the ice, and can break windows and damage downspouts and gutters. In if the rain is especially heavy, ice can penetrate vulnerable locations in roofs, deforming them and often leading to significant water damage to plaster and drywall materials inside the structure.

Transportation

Ice storms are especially dangerous to the transportation. Major ice storms can paralyze the entire transportation system, including public transportation and airports. Spinouts and accidents frequently number in the hundreds. However, most large ice storms are anticipated and road treatments are possible ahead of time. Smaller events from freezing drizzle only cause minor ice accumulations, but when unforeseen, can be devastating. A thin glaze from freezing drizzle on November 20-21, 2010 resulted in several hundred reported accidents, and at least two fatalities.

4.3.13.4. Potential for cascading effects

Extended power outages

An ice storm that knocks out power becomes much more dangerous as the time to restore service increases. This is especially true of storms that are followed by a rapid drop in temperatures. Residences and facilities dependent on electrical power for heat distribution can become dangerously cold within hours of power loss.

Moreover, it is not uncommon for a major ice storm to be followed by or transition to a heavy snowfall event or blizzard. In these cases, the ice produces the initial critical loading, but then the snow and/or wind acts as the "final straw," resulting in severe and widespread power outages. In these situations, the snowstorm or blizzard is just another link in a chain of cascading hazards already in progress.

Flooding

Depending on hydrological and meteorological conditions, ice storms may prime areas for both flash-flooding, and river flooding. Flash-flood scenarios unfold when the glaze of ice is especially thick, temperatures rise to slightly above freezing, and a period of heavy thunderstorms or heavy rain occurs before the ice can melt. Because of ice restricting flow into storm sewers, falling rain can lead to rapid ponding on roads and low lying areas. If the storm water infrastructure is not obstructed, a heavy glaze on the land will prevent absorption by soils, and will direct falling rain directly into area streams, which may rise rapidly. It should be noted that these scenarios to date are extremely rare, and reports in Minnesota have been highly localized.

River flooding can occur after a major ice storm if a large snowpack had been present and/or additional rain falls over a large area. The melted snow would be the initial cause of rising river levels, which would then be exacerbated by rain falling over ice, and to a lesser extent by the melting ice itself. Like flash-flooding, these situations are not common and would require a convergence of many factors. The main risks would occur during the late winter snowmelt period.

Severe weather

In rare situations, it is possible for ice storms to follow or be followed by a significant severe weather event. November, March, and April are currently the most likely months. Power outages and compromised communications from ice storms may limit situational awareness needed to heed severe weather warnings. A direct hit by a major severe weather event on an area recently affected by an ice storm would further complicate damages and compound clean-up efforts. Similarly, an ice storm following a damaging severe weather event would threaten to worsen the impacts significantly, with additional tree, power, structural, and interior damage possible.

4.3.13.5. Geographic scope of hazard

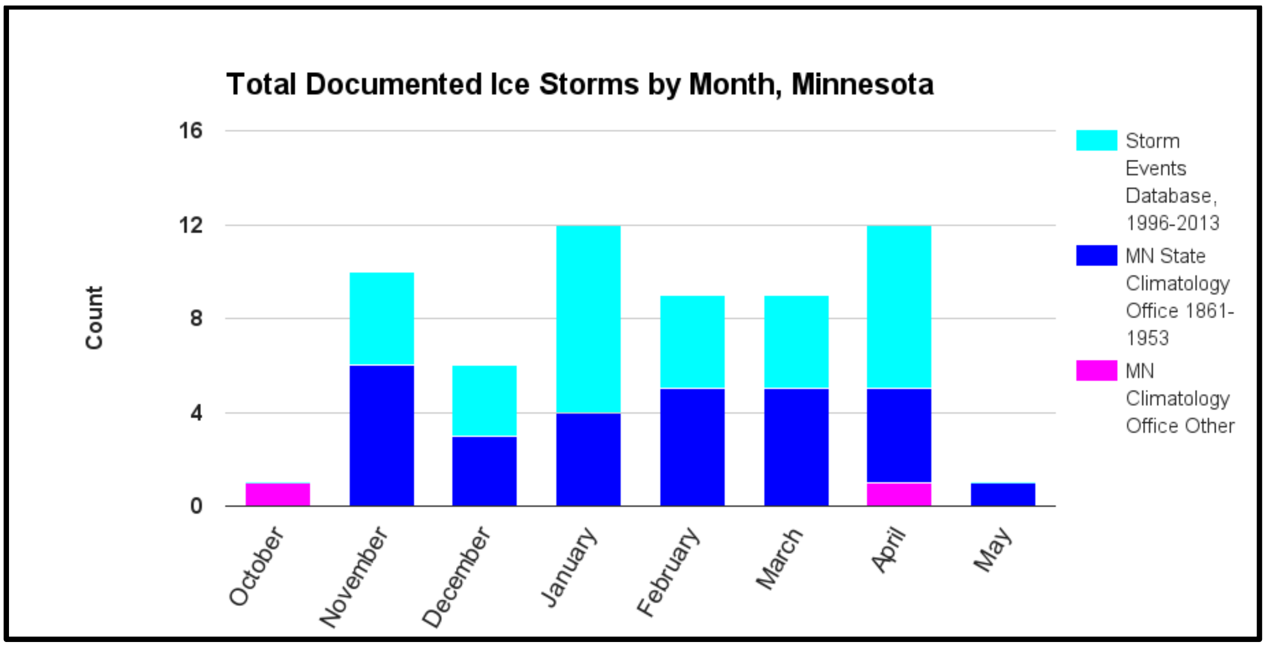
Most major ice storms in Minnesota affect thousands to tens of thousands of square miles--generally an area the size of 10-20 southern Minnesota counties. There have been larger events, and ice storms in the central and southern US often cover 50-100 thousand square miles at a time, with total footprint of up to 250 thousand square miles in some cases.

The State Climatology Office has noted that historically, ice storms have tended to favor higher terrain locations just inland from the north shore of Lake Superior, and along the Buffalo Ridge in southwestern Minnesota. While ice storms have affected every part of Minnesota, these areas have elevated frequencies.

4.3.13.6. Chronologic patterns (seasons, cycles, rhythm)

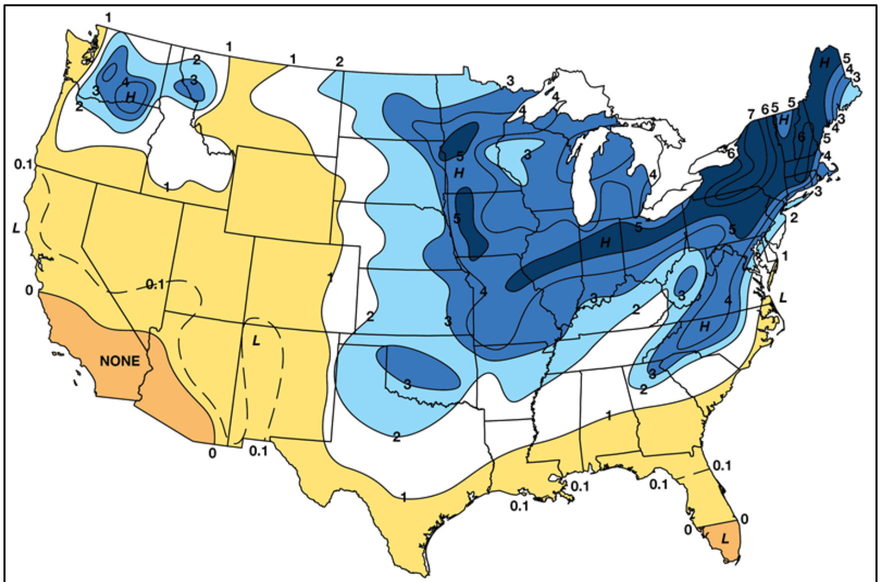
GRAPHIC 4.3.13A shows the peak months, historically, for ice storms in Minnesota are January and April, but the main season should be considered November through April. Rare ice storms have occurred in Minnesota in October and May.

GRAPHIC 4.3.13A



4.3.13.7. Historical (statistical) data/previous occurrence

Historically, most parts of Minnesota have averaged 3-5 days per totaling around 6-9 hours season with freezing rain of some sort. A relative minimum in days per year is found near Hennepin County. It should be noted that freezing rain and freezing drizzle can occur while transitioning to rain, or after a snowfall--either situation dampens the total impact.



The average annual number of days with freezing rain, based on 1948-2000 data. *From Changnon and Karl, 2003.*

The frequency of true ice storms, however, is much lower. Thirty ice storms affected Minnesota in the 20 winter seasons between 1995-96 and 2014-15, yielding an approximate frequency of 1.5 per year. However, ice storms can be highly episodic and clustered in time, with no ice storms in five of those years (25%), and six events during the 1996-97 winter alone.

The following noteworthy ice storms affected various parts of Minnesota:

Feb. 22, 1922.
Blizzard, ice and thunderstorms across Minnesota, with winds hitting 50 mph in Duluth while thunderstorms were reported in the Twin Cities. Heavy ice over southeast Minnesota with 2 inches of ice on wires near Winona. Over two inches of precipitation fell in many areas. This was also one of the largest ice storms in Wisconsin history with ice four inches in diameter on telegraph wires. One foot of ice-covered wire weighed 11 pounds.

Jan. 9-10, 1934.
*S*leet and ice storm over southwest Minnesota. Hardest hit was Slayton, Tracy and Pipestone. The thickest ice was just east of Pipestone with ice measuring 6 to 8 inches in diameter. At Holland in Pipestone County 3 strands of #6 wire measured 4 ½ inches in diameter and weighed 33 ounces per foot. The ice was described as: “very peculiar in formation being practically round on three sides, the lower side being ragged projectiles like icicles: in other words pointed. The frost and ice were wet, not flaky like frost usually is. In handling this, it could be squeezed into a ball and did not crumble.”

March 3-5, 1935*.*

Called "the worst ice storm in Duluth's history," the area covered by this storm was centered on Duluth and extended up the Lake Superior coast to Beaver Bay, and east to Ashland, WI. The worst of the storm extended about 40 miles to the west and south of Duluth.

The storm began in the evening of March 3, with rain and wet snow falling at the Duluth Weather Bureau, and a temperature of 26 degrees. By morning the snow stopped but the rain continued. Ice had accumulated to ⅜ inches by 11 AM and ⅞ inches at 4PM, at which point the lights started going out. By the morning of the 5th, ice coatings were measured at 1.5 inches and Duluth was virtually cut off from the outside world, except for short wave radio. A local ham radio operator sent the Duluth Weather Bureau reports. Four streetcars had to be abandoned in the storm, three of them in the western part of the city. A heavy salt mixture and pick axes were used to try to free the stuck streetcars. A one-mile stretch of telephone poles along Thompson's Hill was "broken off as if they were toothpicks" due to the ice. A Duluth, Masabi & Northern Railway engineer estimated up to 7 inches of ice on cables in Proctor. 75% of shade trees were reported ruined in Moose Lake, with thousands of trees stripped of their limbs. Hibbing also had damage due to ice with the breaking of large and small branches. The Portal Telephone Company in the city of Superior, Wisconsin noted ice from ½ to 1 ½ inches in diameter.

Nov. 10-11, 1940

(Armistice Day Storm). This destructive storm also produced up to ½ inch of ice on wires with ice thickness to 1 inch in Pine City and Lake Benton. Combined with fierce winds, damage to power poles was widespread. In correspondence with M.R. Hovde, the meteorologist in charge of the US Weather Bureau Office, Northwestern Bell reported:

- *Northwestern Bell and Tri-State Telephone & telegraph Company Repairs and Replacements. $79,000 total estimated cost.*
- *Thickness of ice on wires- Generally 1/8 to 1/2 inch diameter. 1 inch in diameter in two small areas.*
- *Time ice first began to form- Early morning of November 11, 1940*
- *Length of time ice remained on wires- About 24 hours*
- *Locality of heaviest ice formation- 1-inch diameter in small area near Pine City. 1-inch diameter in vicinity of Lake Benton.*
- *Approximate number of wires down -1600*
- *Approximate number of pole down -2400*
- *Extent of delay of service- Average 18 hours for toll and 36 hours for exchange lines out of service.*
- *Remarks: The above covers damage to both Northwestern Bell and Tri-State Telephone Company plant in Minnesota. The greatest damage was in the area about 20 miles east and west of a line from Sandstone to Albert Lea.*

Jan. 14, 1952*.*

Glaze, sleet and ice storm across Minnesota from St Cloud south into Iowa. 1,100 Northwestern Bell telephone wires down. The Buffalo Ridge in the Pipestone area the hardest hit with ¾ inches of solid ice on Northern State Power wires with icicles to 3 inches. Northwestern Bell reported ice to 1 ½ inches of ice on their wires in the same area. Thunder and a shower of ice pellets accompanied the storm in New Ulm and Mankato. Minneapolis General Hospital treated 81 victims of falls on icy streets.

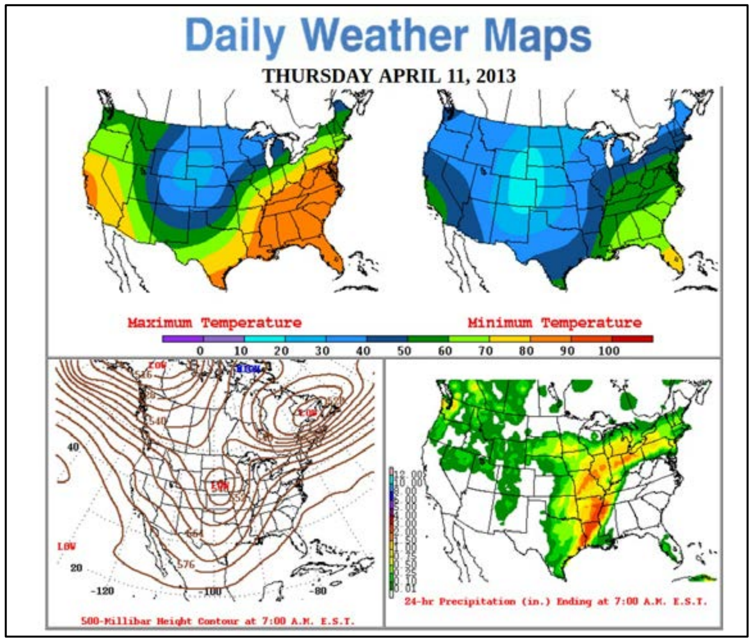
North Shore Ice Storm, March 23-24, 2009.

A vigorous area of low pressure moved out of western Nebraska on March 22, and an area of moderate rain reached northeast Minnesota after midnight on March 23rd. The surface air was warm enough in places like Ely and Hibbing for only minor ice accumulations. However, along the north shore of Lake Superior, near-surface air temperatures remained below freezing. Moderate rain continued through the day and tapered off by the early morning hours of March 24th. Two-day precipitation totals include .91 inches at Grand Marais and 1.94 inches at Duluth. The .91 inches at Grand Marais was freezing rain.

Power outages began as tree branches snapped and downed power lines. Some of the places hardest hit were Two Harbors, Finland, and Grand Marais. 2,000 people were without power in Lake County. The crashing sounds of tree branches could be heard in the woods at Wolf Ridge Environmental Learning Center.

November 20-21, 2010.

A dangerous weather situation set up late on Saturday November 20th and into early Sunday morning the 21st, as freezing drizzle and light freezing rain spread northward. Although ice accumulations were very light, the glaze caused treacherous driving conditions, resulting in over 400 accidents and two deaths in Minnesota.



Southwest Minnesota Ice Storm, April 9-11, 2013.

A slow-moving low pressure system pumped copious amounts of moisture up into a subfreezing air mass, resulting in up to 48 hours of nearly continuous freezing rain in southwestern Minnesota, eastern Nebraska, northwestern Iowa, and eastern South Dakota. Just north of the freezing rain, heavy, wet snow accumulated 6-14 inches. In southwestern Minnesota, hundreds of trees and power poles were snapped by the ice, which accumulated to nearly 1" thick near Worthington. Extensive secondary damage occurred to residences and vehicles, as tree limbs snapped off and crashed through windows. Power outages lasted days in some areas. Governor Dayton issued Executive Order 13-03, to authorize state assistance for recovery efforts in southwestern Minnesota.

4.3.13.8. Future trends/likelihood of occurrence

Little is known about future trends with respect to ice storm activity. On one hand, damaging ice storm frequency may decrease, as more and more winter events fall as above-freezing liquid. Another argument is that more events that would have been snowstorms will contain freezing rain, and hence, more ice storms. Yet another line of reasoning suggests that increased wintertime moisture will result in more heavy precipitation events, including heavy rain and freezing rain. The topic has received little research attention, so there is virtually no "consensus" about what is likely to happen.

4.2.13.9. Indications and Forecasting

The Twin Cities/Chanhassen forecast office of the National Weather Service is the official forecasting authority for major winter weather events affecting Hennepin County, including ice storms. High-intensity winter storms are usually well anticipated by the numerical weather prediction models, often up to a week in advance, and forecasters tend to have high awareness of potentially dangerous winter conditions two days or more before they develop. The potential for significant ice accumulation 1-3 days out is also monitored by the Weather Prediction Center, at NOAA/NWS headquarters.

4.3.13.10. Detection & Warning

Warning authority for ice storms also lies with the Twin Cities/Chanhassen forecast office of the National Weather Service. An urgently severe ice storm will be covered by an Ice Storm Warning, which indicates over .25" of ice accumulation is expected. These situations may lead to damage and power outages, in addition to dangerous or impossible travel. Lesser accumulations of ice will be covered by a Freezing Rain Advisory. In these conditions, travel may still be dangerous or impossible, but damage is significantly less likely.

If a severe ice storm is expected with other winter hazards, especially snow, the NWS may cover all hazards under a Winter Storm Warning. Similarly, lesser ice accumulations with lighter accumulating snow may be covered under a Winter Weather Advisory.

4.3.13.11. Critical values and thresholds

Ice storm or Winter Storm Warnings will be issued when over ¼ inch of ice accumulation is expected. Damage to trees, along with power outages, increase dramatically after ½" of ice accumulation.

4.3.13.12. Preparedness

Because ice storms are likely to disrupt power and disable local transportation routes, before the storm strikes, homes, offices and vehicles should be stocked with needed supplies. At home or work, primary concerns are loss of heat, power and telephone service, and a shortage of supplies in prolonged or especially severe and disruptive events.

Essential Supplies

- Flashlight and extra batteries
- Battery-powered NOAA Weather Radio and portable radio to receive emergency information
- Extra food and water such as dried fruit, nuts and granola bars, and other food requiring no cooking or refrigeration.
- Extra prescription medicine
- Baby items such as diapers and formula
- First-aid supplies
- Heating fuel
- Emergency heat source: properly ventilated fireplace, wood stove, or space heater
- Fire extinguisher, smoke alarm; test smoke alarms once a month to ensure they work properly
- Extra pet food and warm shelter for pets
- Back-up generator (optional) but never run a generator in an enclosed space
- Carbon monoxide detector
- Outside vents should be clear of leaves, and debris, and cleared of snow after the storm.

4.3.13.13. Mitigation

Education and Awareness Programs

- Vehicle fleet crews and others who spend substantial time on the road should be familiar with NWS warning products, jurisdictions, and be familiar with how to obtain pertinent information. All professional drivers should carry winter weather survival supplies.
- Members of the general public should understand the risks posed by winter storms, and should review the information available at https://dps.mn.gov/divisions/hsem/weather-awareness-preparedness/Pages/winter-storms.aspx.

4.3.13.14. Recovery

Recovery from a major ice storm can take days, or even weeks if it is complicated by a combination of other weather hazards. In forested areas, logging activities may be significantly impacted, and fuel loads from fallen trees may exacerbate the potential for wildland fire. In addition to power outages, persistent wind loading on structures, associated with powerful winter storms, has at times caused gas line ruptures.

4.3.13.15. References

Changnon, S. A., & Karl, T. R. (2003, 09). Temporal and Spatial Variations of Freezing Rain in the Contiguous United States: 1948–2000. *Journal of Applied Meteorology J. Appl. Meteor., 42*(9), 1302-1315. doi:10.1175/1520-0450(2003)0422.0.co;2

Homeland Security and Emergency Management. (n.d.). Retrieved April 11, 2016, from https://dps.mn.gov/divisions/hsem/weather-awareness-preparedness/Pages/winter-storms.aspx

Ice Storm - Southwest Minnesota: April 9-10, 2013. (n.d.). Retrieved April 11, 2016, from http://www.dnr.state.mn.us/climate/journal/130410_winter_storm.html

Ice Storms. (n.d.). Retrieved April 11, 2016, from http://mrcc.isws.illinois.edu/living_wx/icestorms/ North Shore Ice Storm: March 23-24 2009. (n.d.). Retrieved April 11, 2016, from http://climate.umn.edu/doc/journal/Ice_storm090323_24.htm

Overview of Extensive Ice Storms in Minnesota, retrieved from http://files.dnr.state.mn.us/natural_resources/climate/summaries_and_publications/ice_storms_in_minnesota.pdf

SECTION 5	HUMAN CAUSED TECHNICAL/INDUSTRIAL HAZARD ASSESSMENT

Building out in 2018

SECTION 6	HUMAN CAUSED ADVERSARIAL HAZARD ASSESSMENT

Building out in 2018

SECTION 7	MASS EVACUEE AND IMMIGRATION MOVEMENT

Building out in 2018

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SECTION 8	VULNERABILITY ASSESSMENT

After hazards were identified, they were given a ranking of “high”, “medium” or “low”. This was based on their probability of occurrence, their impact on population, critical infrastructure and the economy. Each participating municipality may have differing degrees of risk exposure and vulnerability compared to others due their geographic proximity to the hazard. However, many of the hazards are countywide risks due to their size and their impacts, and because not all are geographically specific. Under each map portion is a hazard ranking justification statement of why the hazard was given the ranking it received.

8.1 Hazard Ranking Maps

The following pages provide hazard rankings (in alphabetical order) for the following hazards:

GRAPHIC 8.1A Blizzard

Hazard Ranking Justification

Occurrences, impacts and land use were all used in the methodology for ranking Blizzards as a hazard in Hennepin County. Hennepin County has winter storms with high winds occur each year, and being blizzards are the most dangerous class of winter storms, they come with high impacts. In addition to blizzard conditions occurring each year in Minnesota, the MLCCS Hennepin County Land Cover map was used to determine areas of Hennepin County with artificial surface. These artificial surfaces are strongly associated with where buildings and higher populated areas are. The areas with less than 50% artificial surfaces were ranked at higher risks for blizzards because they are more susceptible to high winds and blowing snow with visibilities less than ¼ mile. It is tougher, although not impossible, to get visibility less than ¼ with areas that are built up more because of building blocking wind and blowing snow.

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Publication date: 11/2/2016

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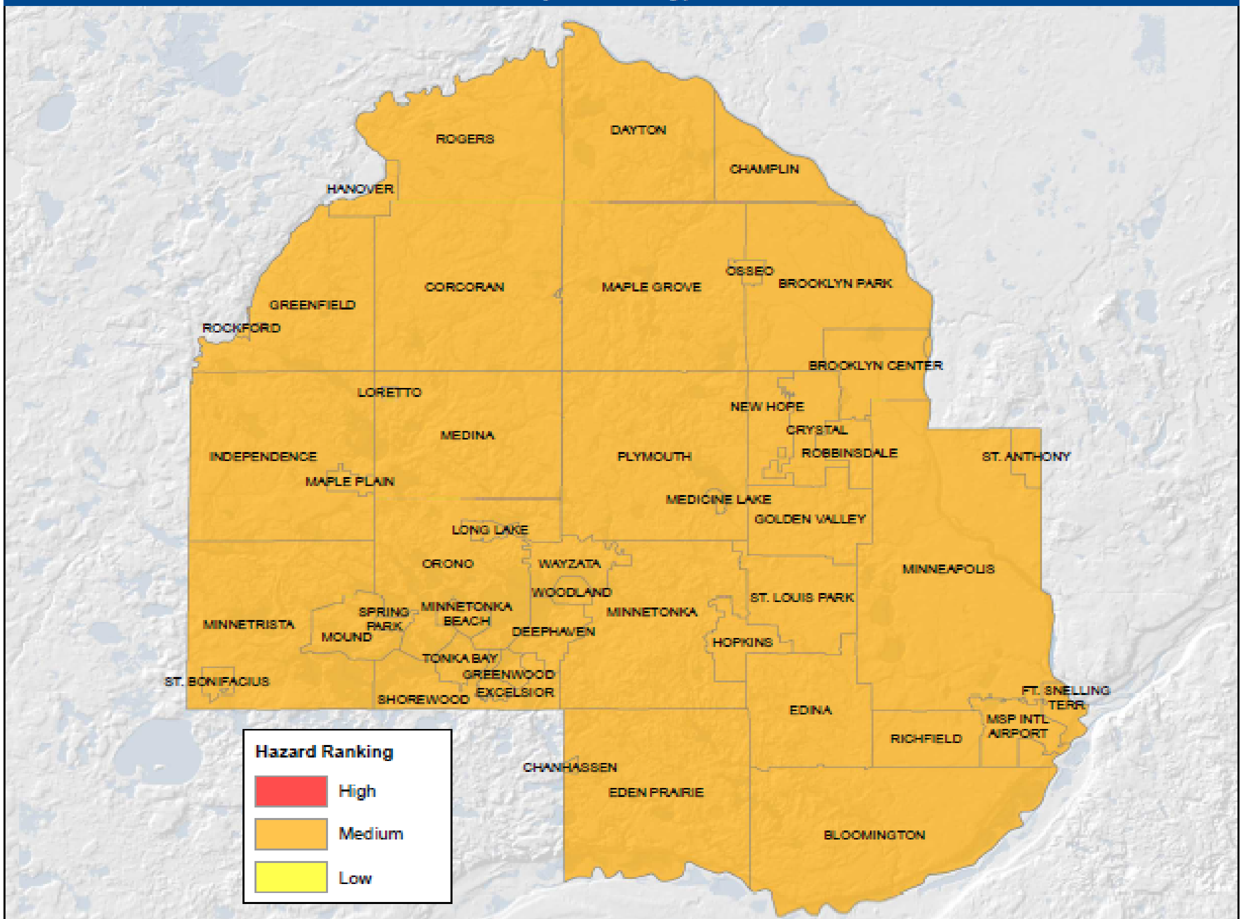
Hennepin County Emergency Management

GRAPHIC 8.1B Climate Change

Climate Change Hazard Ranking

Hennepin County, MN



Hazard Ranking Justification

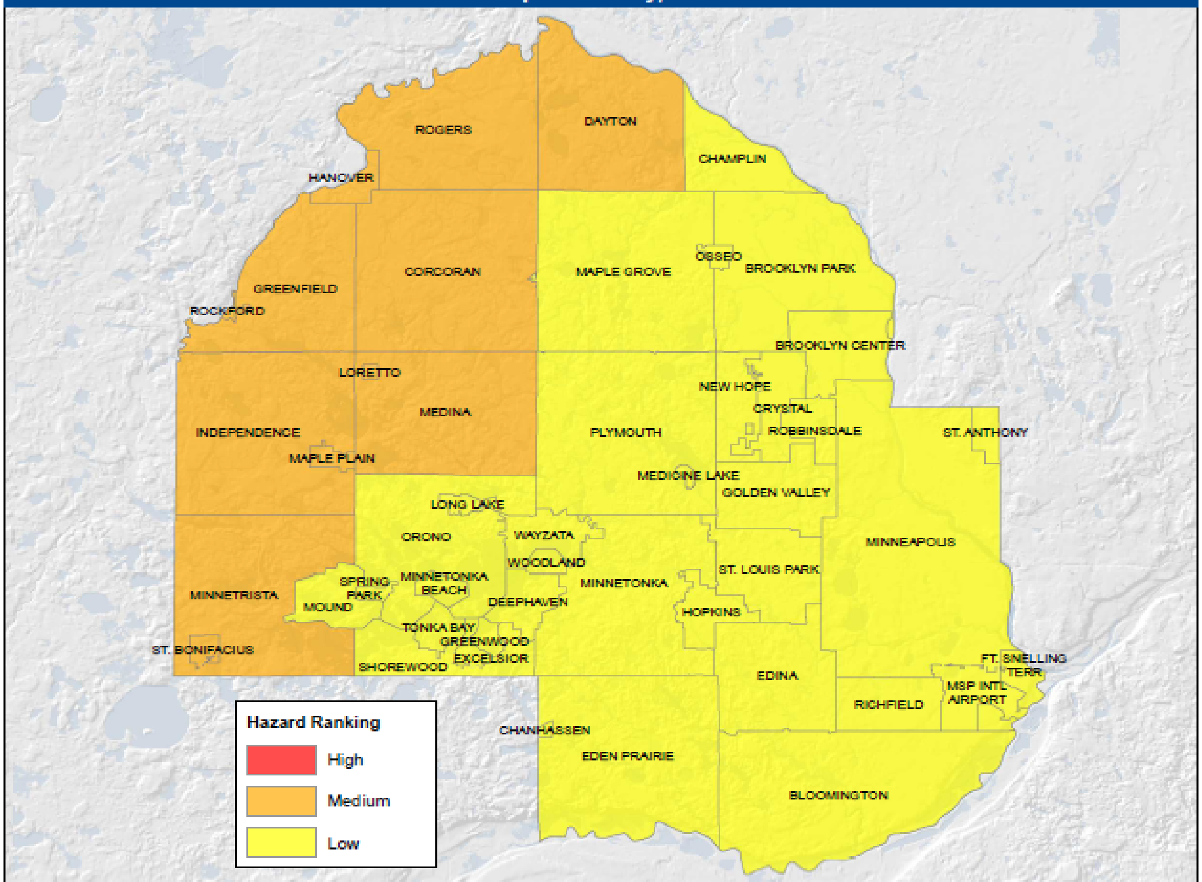
Impacts, its long lasting consequences, and time onset were the primary methods used in ranking Climate Change as a hazard in Hennepin County. Unlike other hazards, climate change is slow onset and we will not see day to day consequences, but long term consequences. Reasoning behind why because of this slow onset that climate change across Hennepin County is ranked as medium is because of the impacts and consequences as it applies to other hazards within Hennepin County.

Hennepin County 2015 Mitigation Plan
Publication date: 11/4/2016

Hennepin County Emergency Management

GRAPHIC 8.1C Disease, Animal Infectious

Disease, Animal Infectious Hazard Ranking
Hennepin County, MN



Hazard Ranking Justification

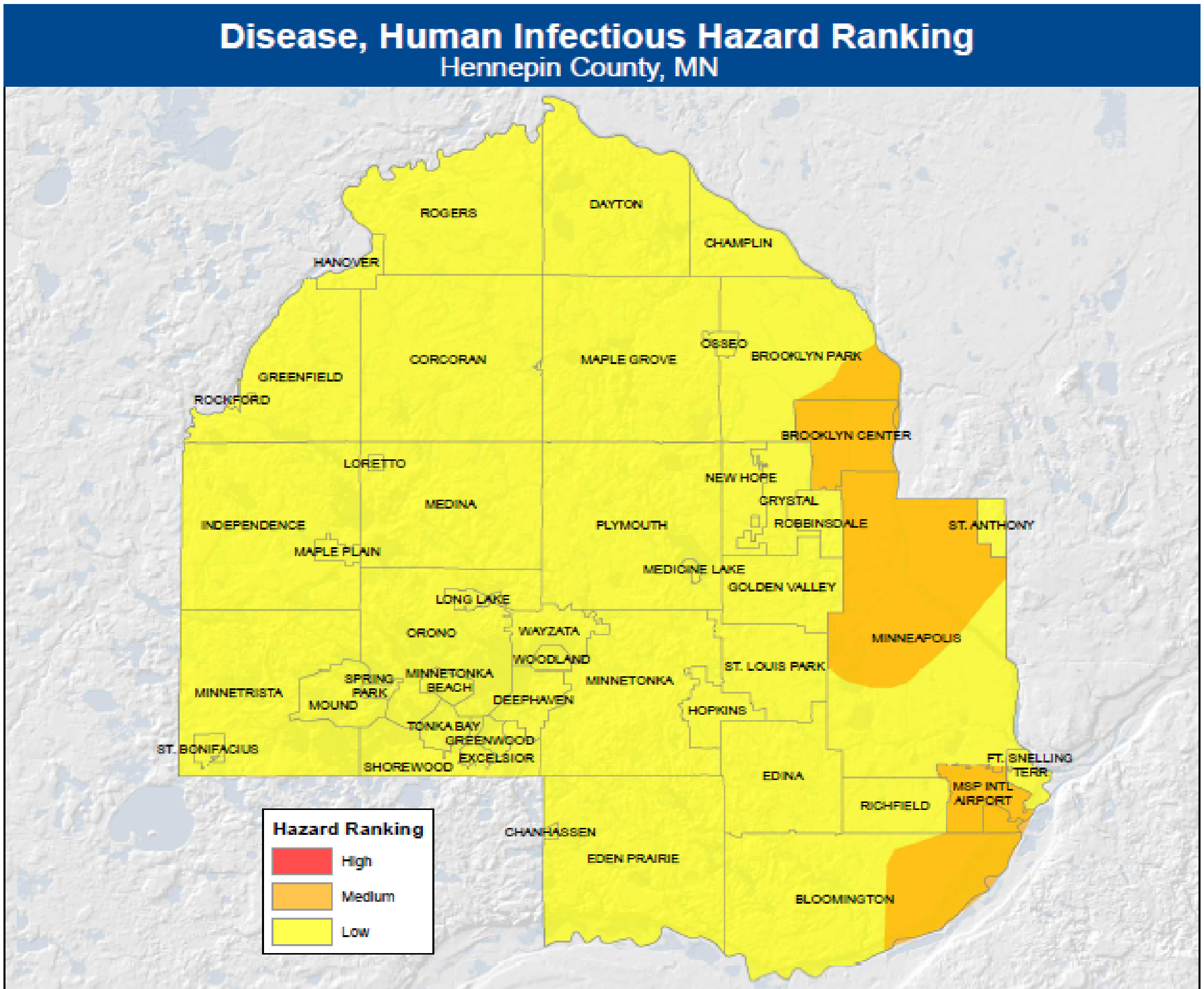
Geographic hazards include livestock for consumption and hobby farms. There are a variety of common illness that are spread through infected populations in the form of parasites, fungal infection and bacterium found in rodents. 70% of the emerging diseases have a connection to wildlife and oversight to monitor this population is not resourced but rather reactive when a surge of disease manifests itself in the wild. Western Hennepin County favors a higher probability of animal disease due to the environmental factors and land usage.

Hennepin County 2015 Mitigation Plan
Publication date: 11/4/2016

Hennepin County Emergency Management

Hennepin

GRAPHIC 8.1D Disease, Human Infectious



Hazard Ranking Justification

Emerging infectious disease in the human populace are caused by organisms (bacteria, virus, fungi or parasite). Transmission can be Direct (person to person, animal to person and mother to child) or Indirect (insect bites, contamination of food and water or exposure in the environment). Hennepin County is susceptible to infectious disease through any of these factors. Typically higher concentrations of people in an area provides a higher probability of communicable disease.

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Publication date: 11/8/2016

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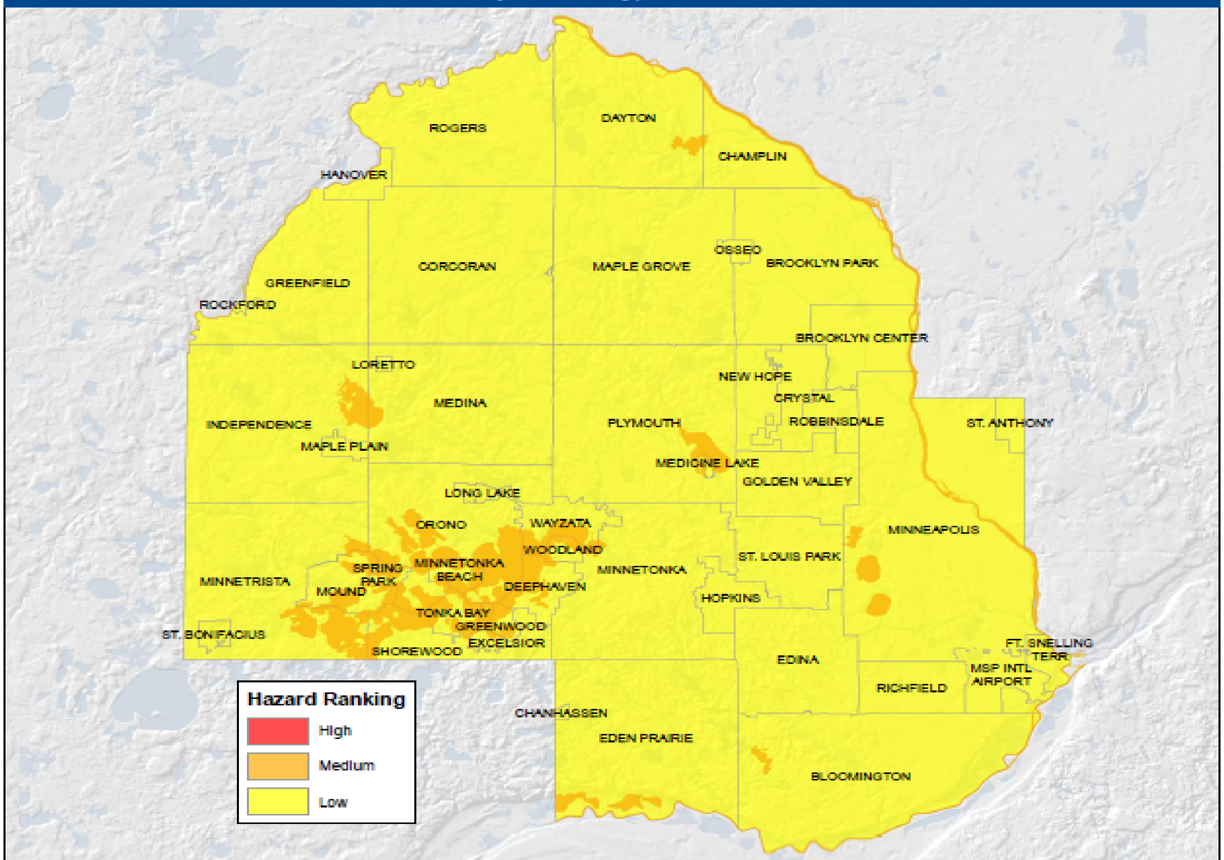
Hennepin County Emergency Management

Hennepin

GRAPHIC 8.1E Disease, Insect Infectious

Disease, Insect Infectious Hazard Ranking
Hennepin County, MN



Hazard Ranking Justification

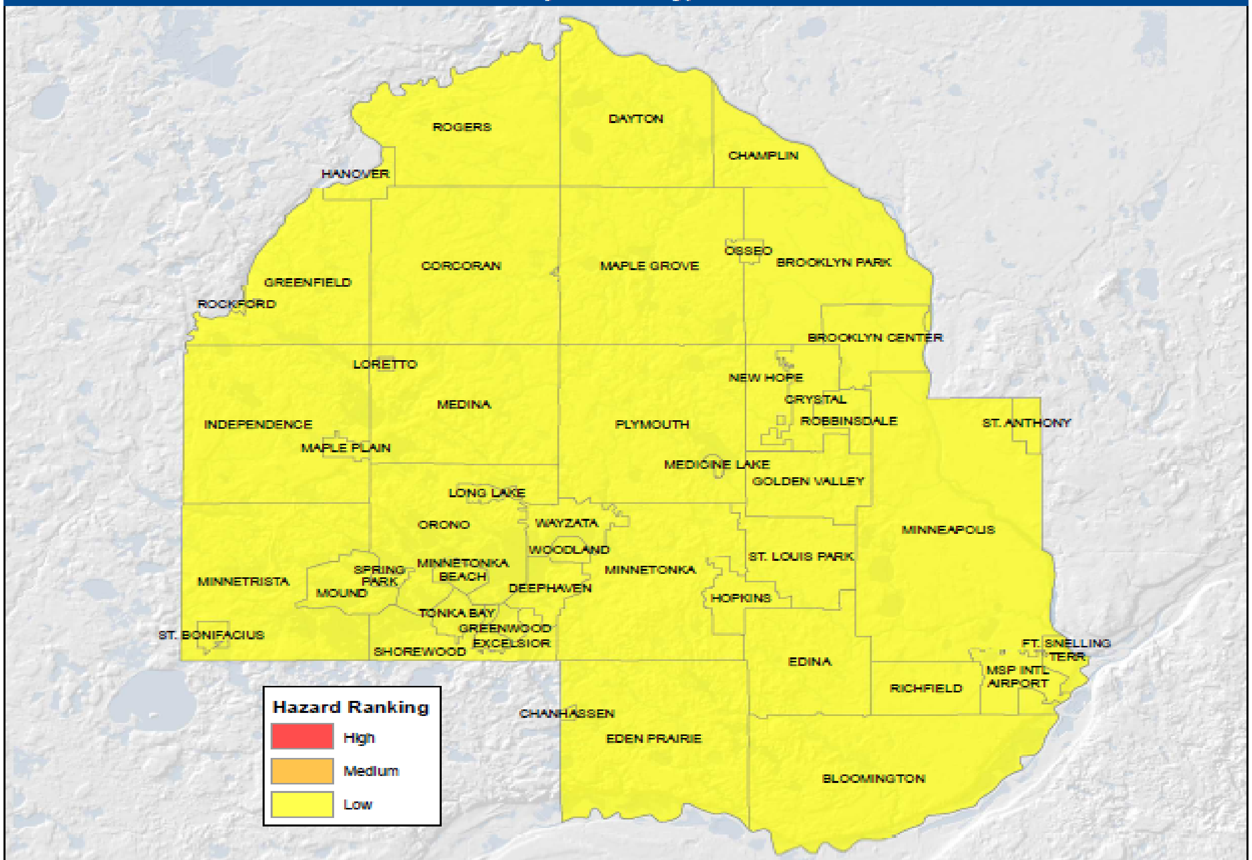
Infestation is classified as internal or external. Hennepin County considers insect infestation as it relates to crop yield and growth cycles in farming. It also looks at bodies of water where many insect habitats develop. March to October typically produces most of the species that develop due to the warmer climatic factors.

Hennepin County 2015 Mitigation Plan
Publication date: 11/4/2016

Hennepin County Emergency Management

GRAPHIC 8.1F Disease, Plant Infectious

Disease, Plant Infectious Hazard Ranking
Hennepin County, MN



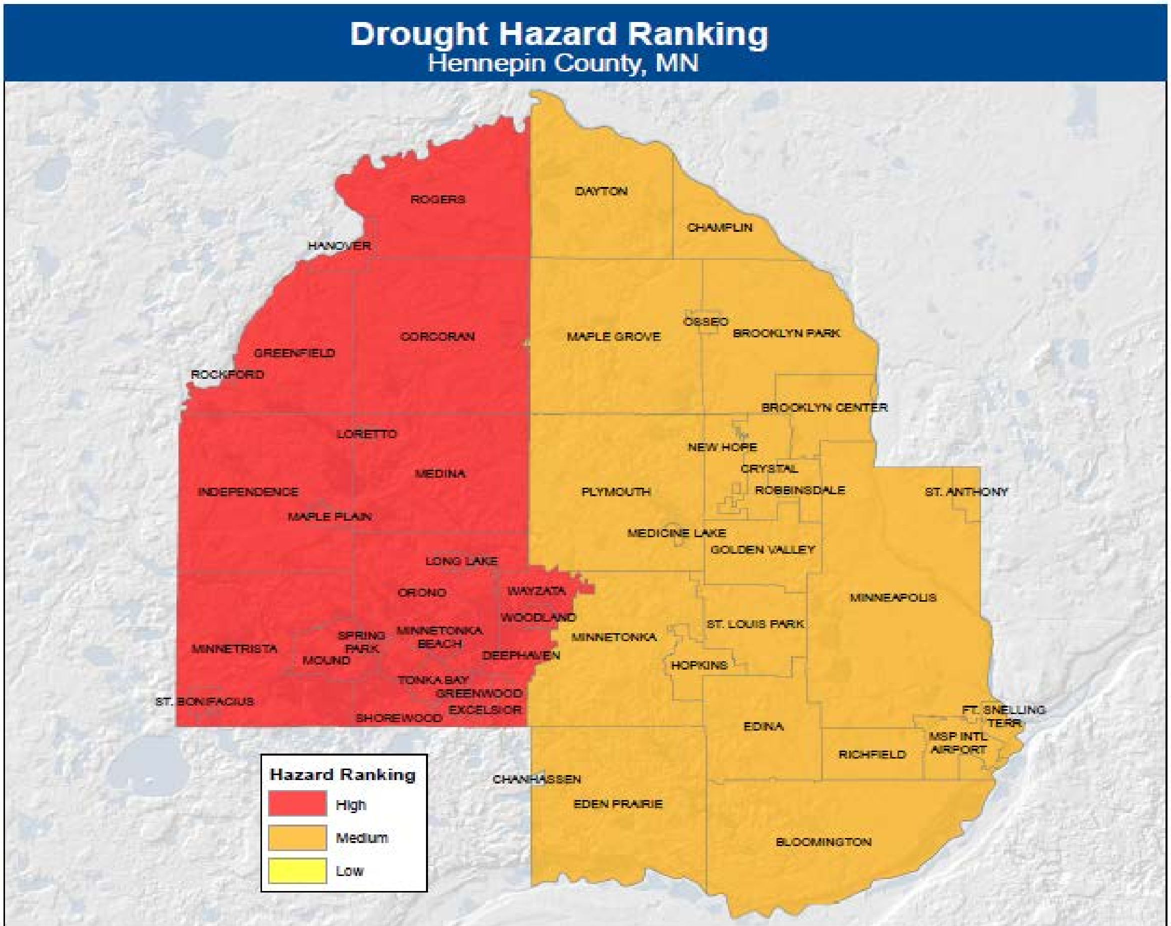
Hazard Ranking Justification

Currently Hennepin County does not have a strong reference of research to determine where plant disease may harm the human or wildlife populace, farm animals, insects or the environment.

Hennepin County 2015 Mitigation Plan
Publication date: 11/4/2016

Hennepin County Emergency Management

GRAPHIC 8.1G Drought



Hazard Ranking Justification

Occurrences and impacts were the primary methods used to rank Drought as a hazard across Hennepin County. Every single year, part if not all of Hennepin County is included within a level of drought according to the United State Drought Monitor. Drought can have impacts on many aspects across the county, which is what started the baseline at medium ranking for this hazard. The western side of the county is much more agriculture heavy than the east side, which can have more impacts and consequences because of drought, which is what gave the west side of Hennepin County a high ranking.

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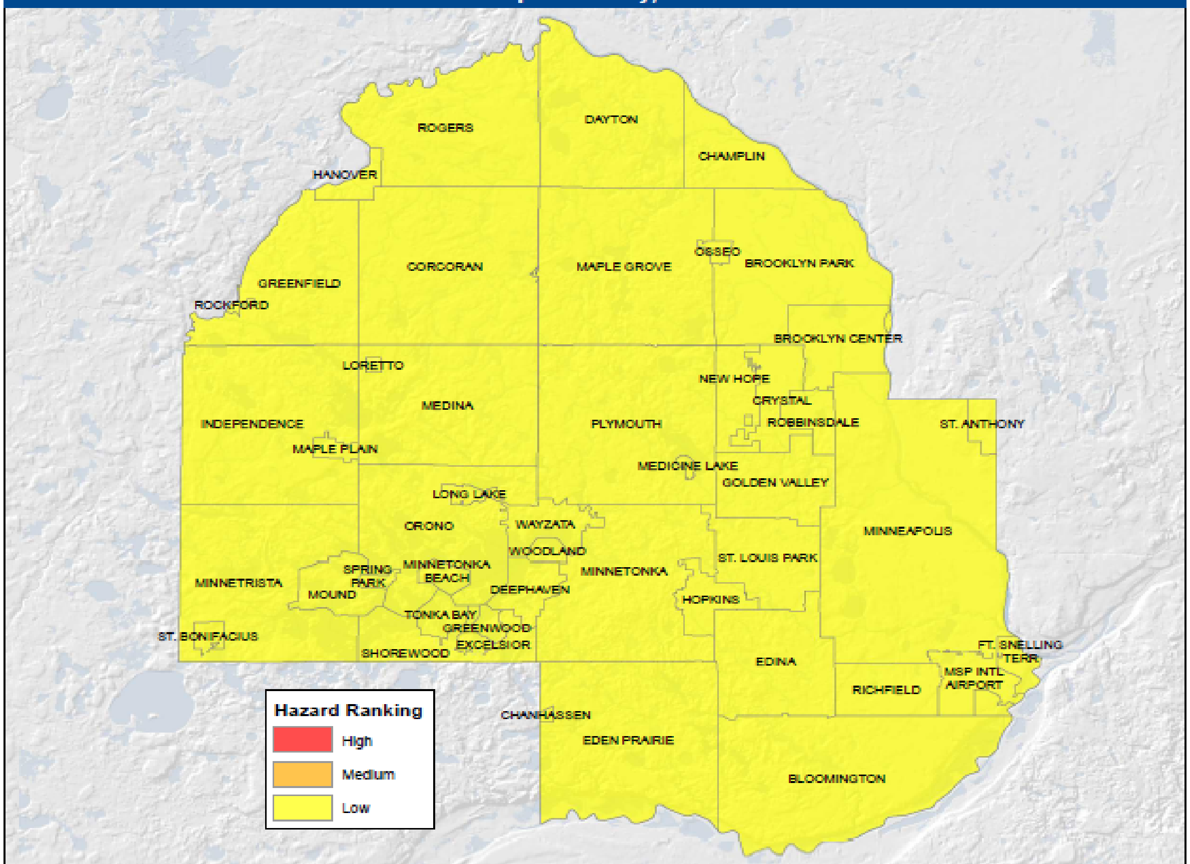
Publication date: 11/7/2016

Hennepin County Emergency Management

GRAPHIC 8.1H Dust Storms

Dust Storms Hazard Ranking
Hennepin County, MN



Hazard Ranking Justification

Occurrences and historical data were the primary methods used to rank Dust Storms as a hazard across Hennepin County. Dust storms are rare across Hennepin County. Although they can happen, this low frequency and since we have not seen a true dust storm in many years are the reasons this hazard is ranked low.

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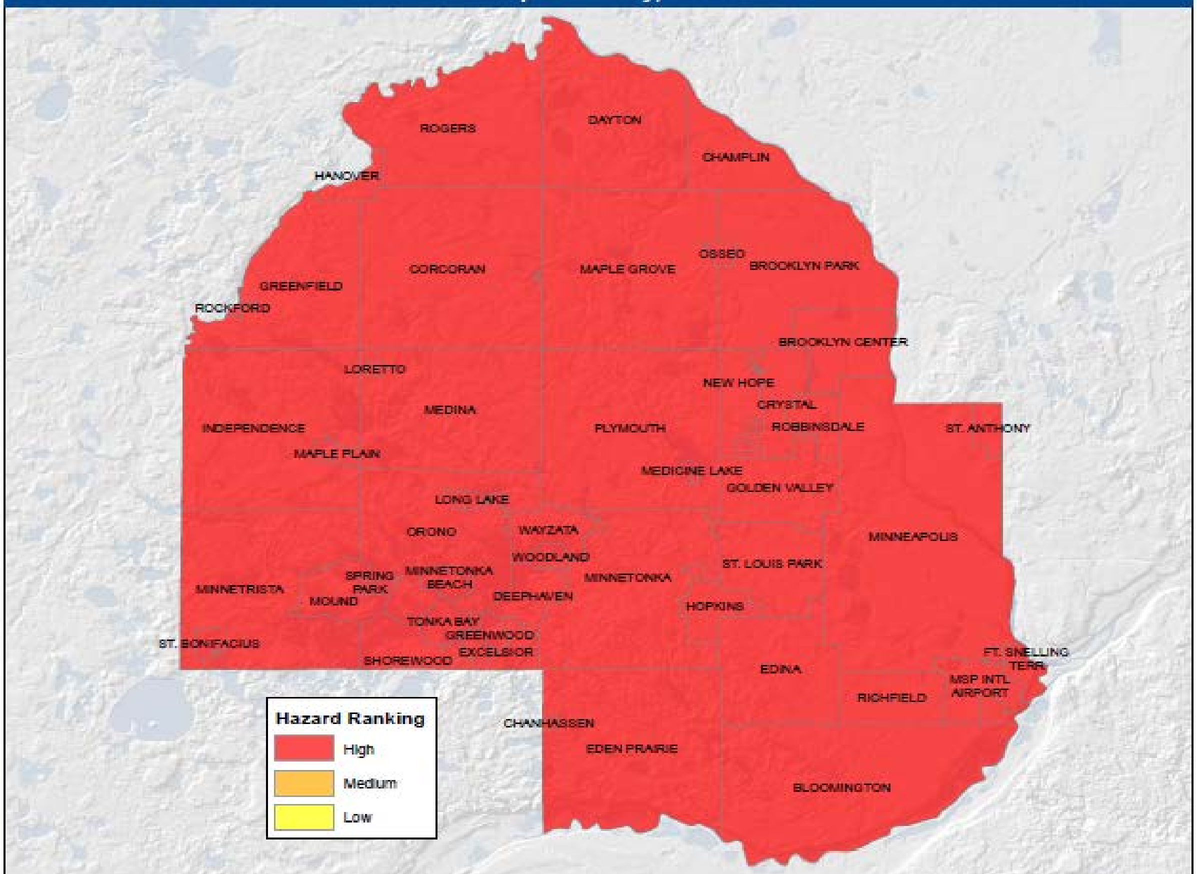
Publication date: 11/7/2016

Hennepin County Emergency Management

GRAPHIC 8.1I Extreme Cold

Extreme Cold Hazard Ranking
Hennepin County, MN



Hazard Ranking Justification

Occurrence and impacts were the primary methods used to rank Extreme Cold as a hazard across Hennepin County. Extreme cold temperatures occur every year across Hennepin County. In addition, they can have extreme consequences and impacts, especially if extreme cold conditions persist for long periods of time.

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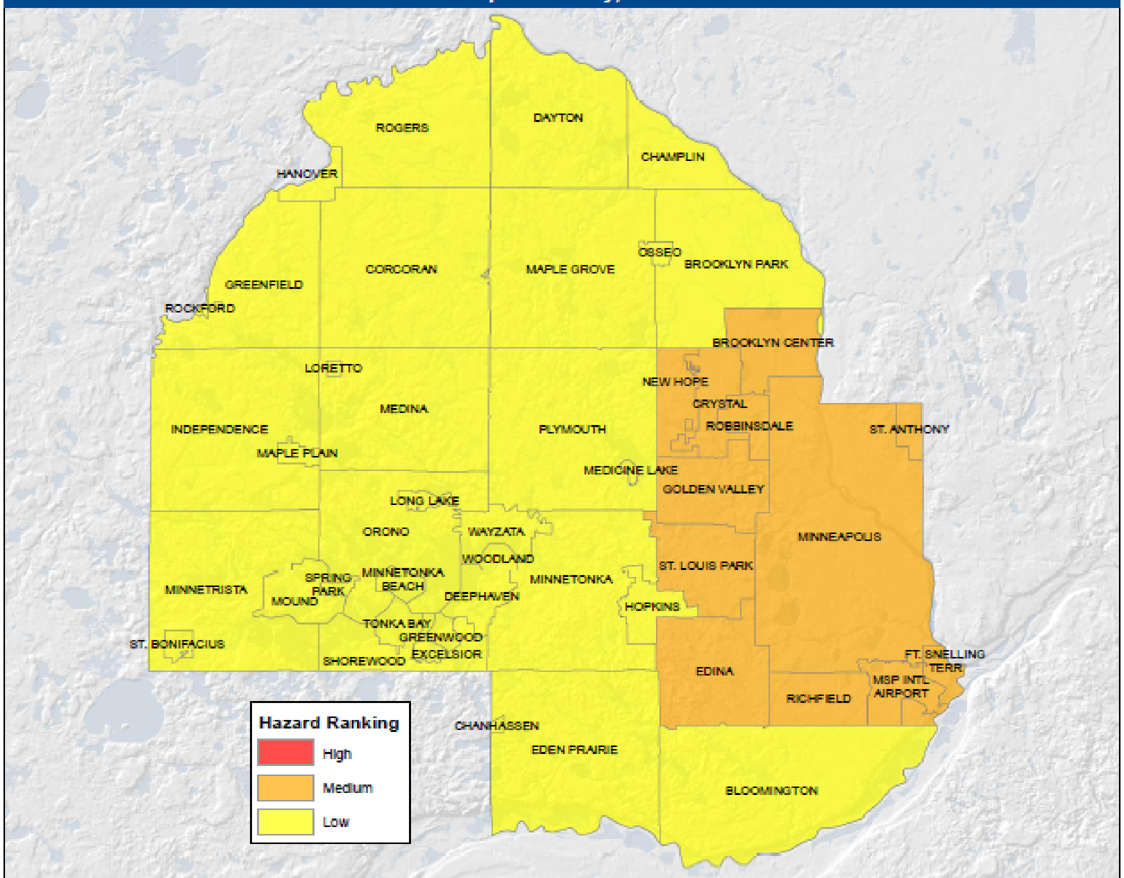
Publication date: 11/7/2016

Hennepin County Emergency Management

GRAPHIC 8.1J Extreme Heat

Extreme Heat Hazard Ranking
Hennepin County, MN



Hazard Ranking Justification

Occurrence, and impacts were the primary methods used to rank Extreme Heat as a hazard across Hennepin County. Hennepin County typically sees around one extreme heat warning each year, that lasts between one and five days. The reasons cities within the eastern part of Hennepin County are ranked medium as opposed to the rest, is these cities are included within the area of the Urban Heat Island.

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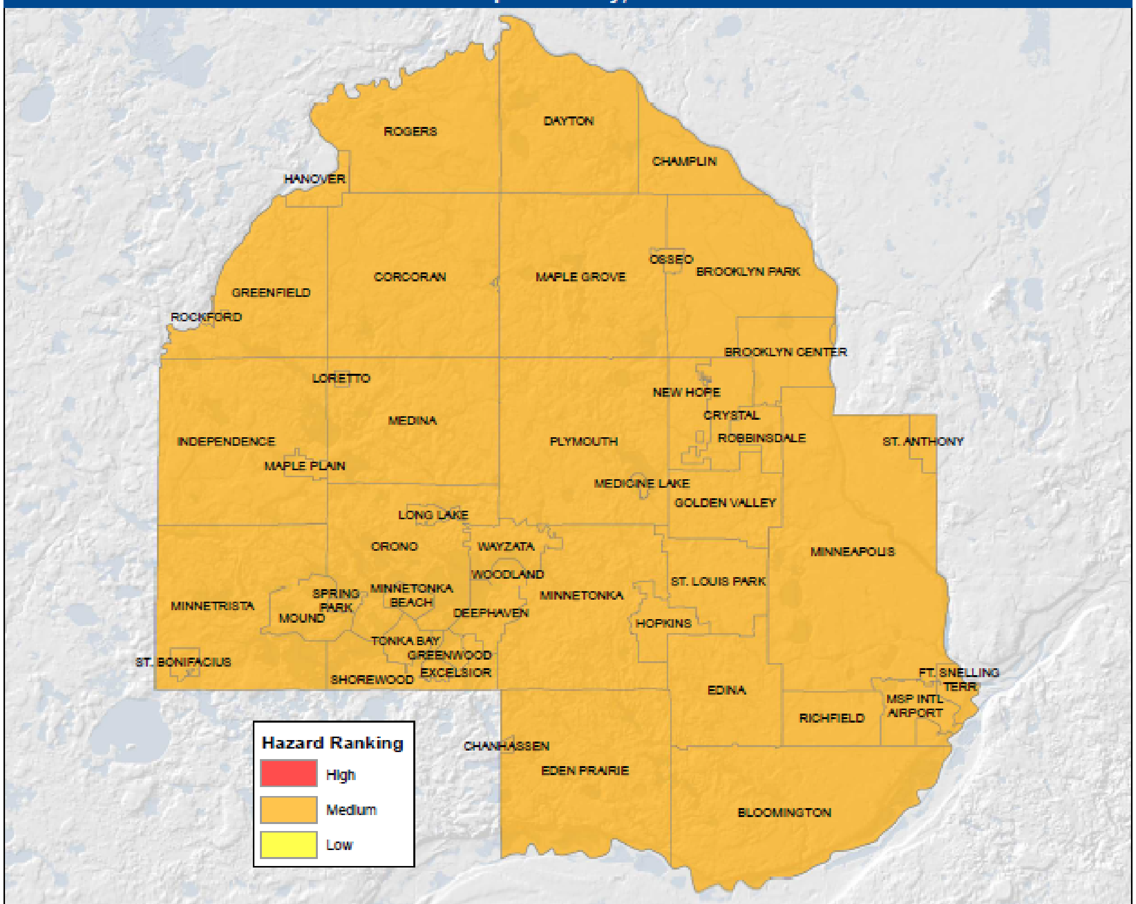
Publication date: 11/7/2016

Hennepin County Emergency Management

Hennepin

GRAPHIC 8.1K Extreme Rainfall

Extreme Rainfall Hazard Ranking
Hennepin County, MN



Hazard Ranking Justification

Occurrence, recent historical disasters and future trends were the primary methods used to rank Extreme Rainfall as a hazard across Hennepin County. Extreme rainfall events can go through more and less active periods, however the threat of them occurs close to every year within Hennepin County. Hennepin County has seen numerous extreme rainfall events in the very short term past. In addition, trends show that these events will likely continue, and possibly get worse. Hennepin County is not projected to see much change in amount of rain we get each month or year, but rather more rainfall at one time versus being spread out over longer periods.

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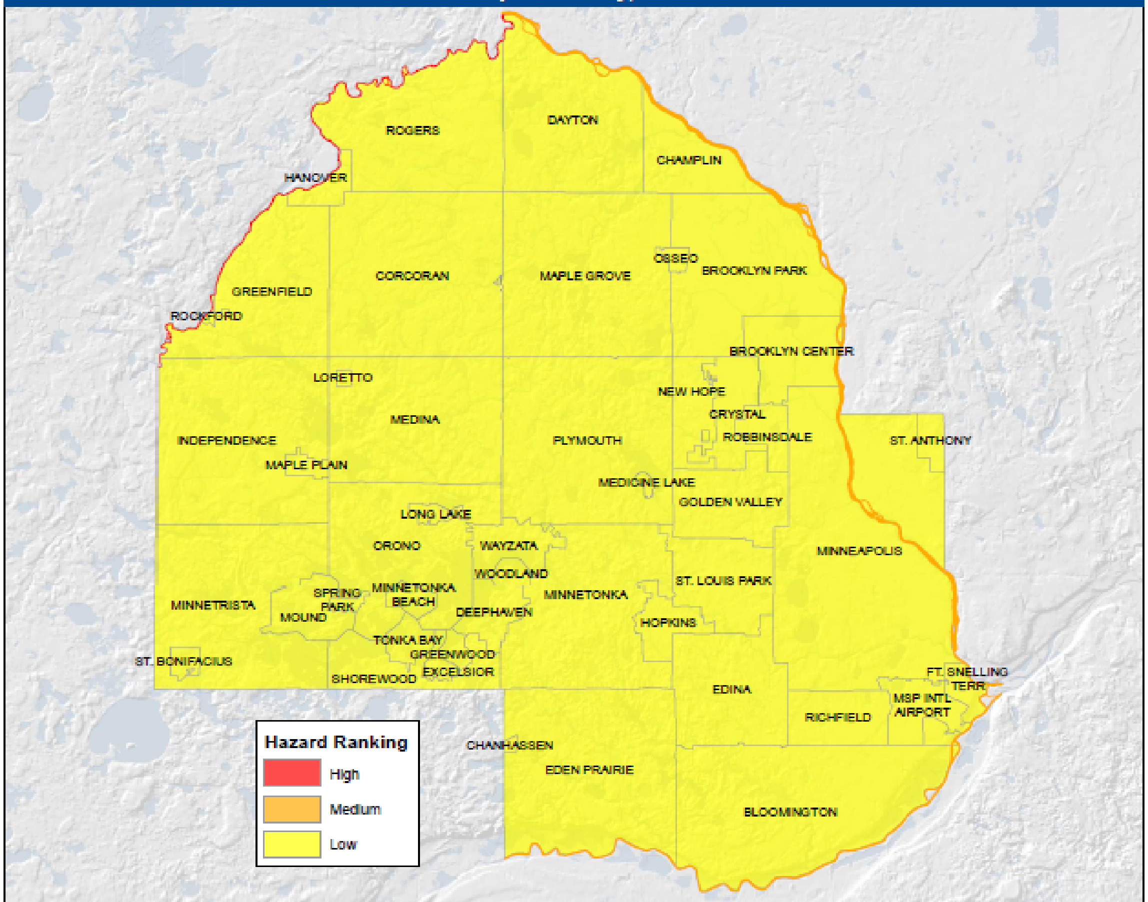
Hennepin County Emergency Management

GRAPHIC 8.1L Flooding, River

Flooding, River Hazard Ranking
Hennepin County, MN



Hazard Ranking Justification

Occurrence, impacts, and the Hennepin County FEMA Floodplains Map were the primary methods used to rank River Flooding as a hazard across Hennepin County. Hennepin County has three major river basins that travel along its boarders: Crow River, Mississippi River, and the Minnesota River. Every year at least one of these rivers has warnings issued. The Crow River on the northwest side of Hennepin County is ranked higher has hazardous than the Mississippi and Minnesota Rivers because the Crow River does not have as high of banks, cliffs associated with it. The FEMA Floodplains Map shows all the rivers being impacted by a 100 year flood. However, there is more infrastructure that could be damaged along the crow more easily than along the Mississippi or the Minnesota Rivers.

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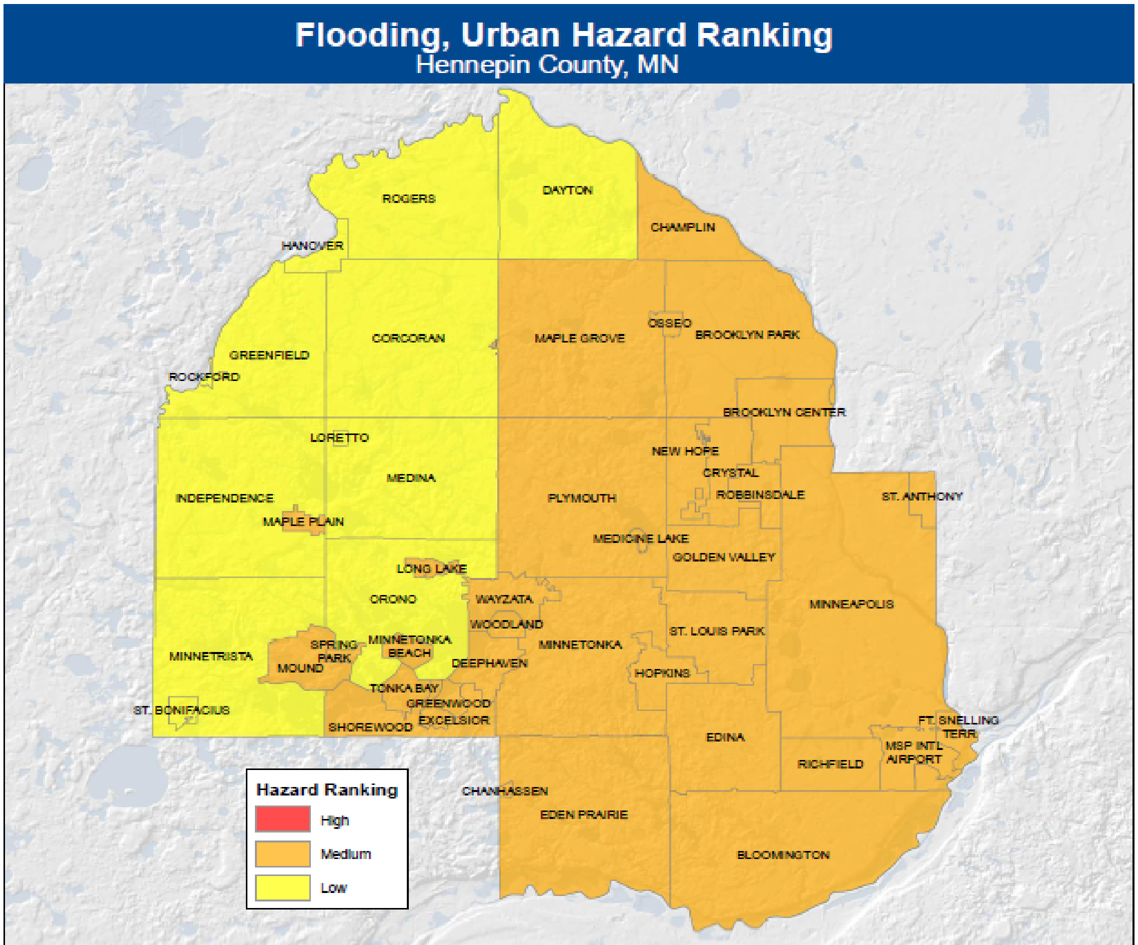
Hennepin County Emergency Management

GRAPHIC 8.1M Flooding, Urban



Hazard Ranking Justification

Land use, and the Hennepin County FEMA Floodplains Map were the primary methods used to rank Urban Flooding as a hazard across Hennepin County. If cities had greater than 50% area covered by artificial services, there were ranked as medium versus low like the rest of the county. This is because the more artificial surface, the more runoff we will see versus infiltration. The FEMA Floodplains Map was used to guide the area around Lake Minnetonka. Every city around the lake looks to be impacted by the 100-year flood.

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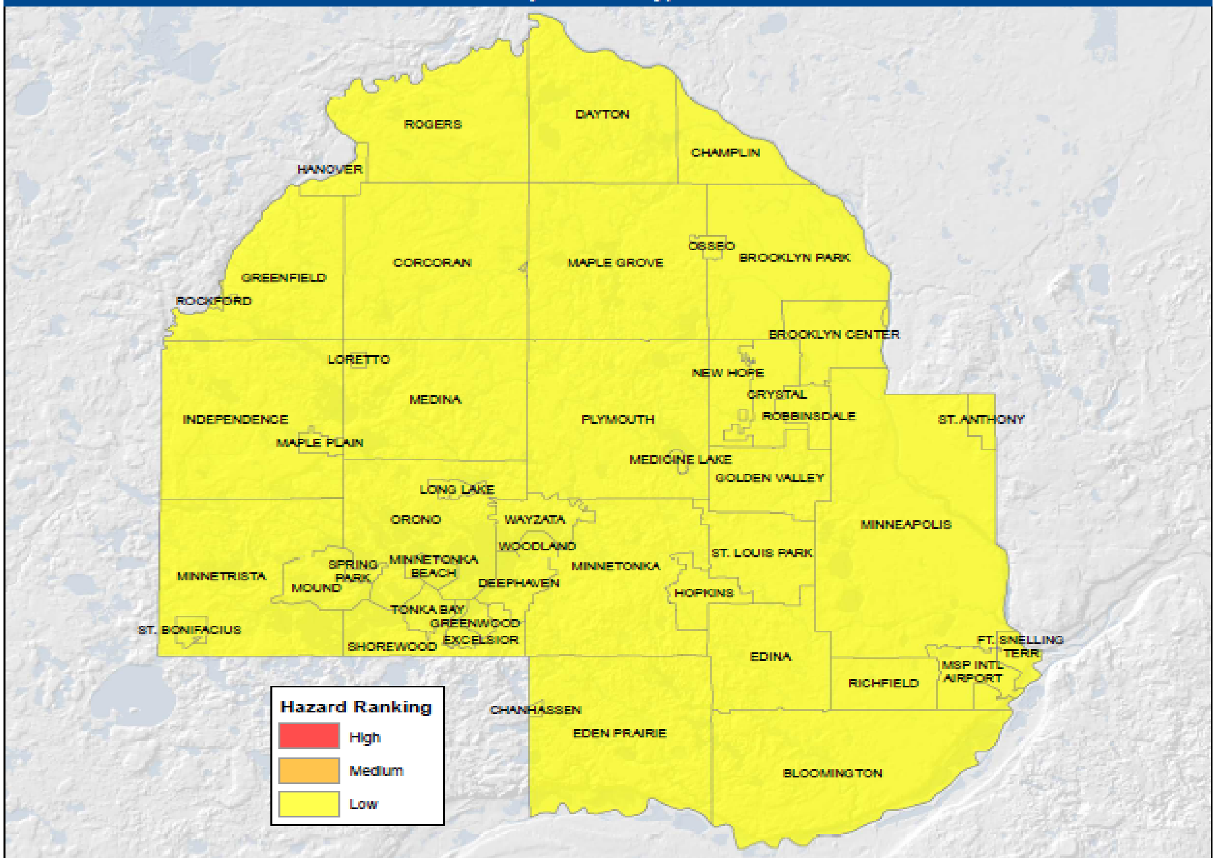
Hennepin County Emergency Management

GRAPHIC 8.1N Hail

Hail Hazard Ranking
Hennepin County, MN



Hazard Ranking Justification

Occurrence, impacts, and historical evidence were the primary methods used to rank Hail as a hazard across Hennepin County. Hail within the borders of Hennepin County occur every year. While we have seen hail in excess of three inches in diameter, the majority of hail occurring within Hennepin County has been less than two inches. In addition, there typically is less of a threat to public infrastructure than private residences with hail storms. While hail storms can cost a lot in damages, those high cost hail storms do not occur within Hennepin County on a frequent basis.

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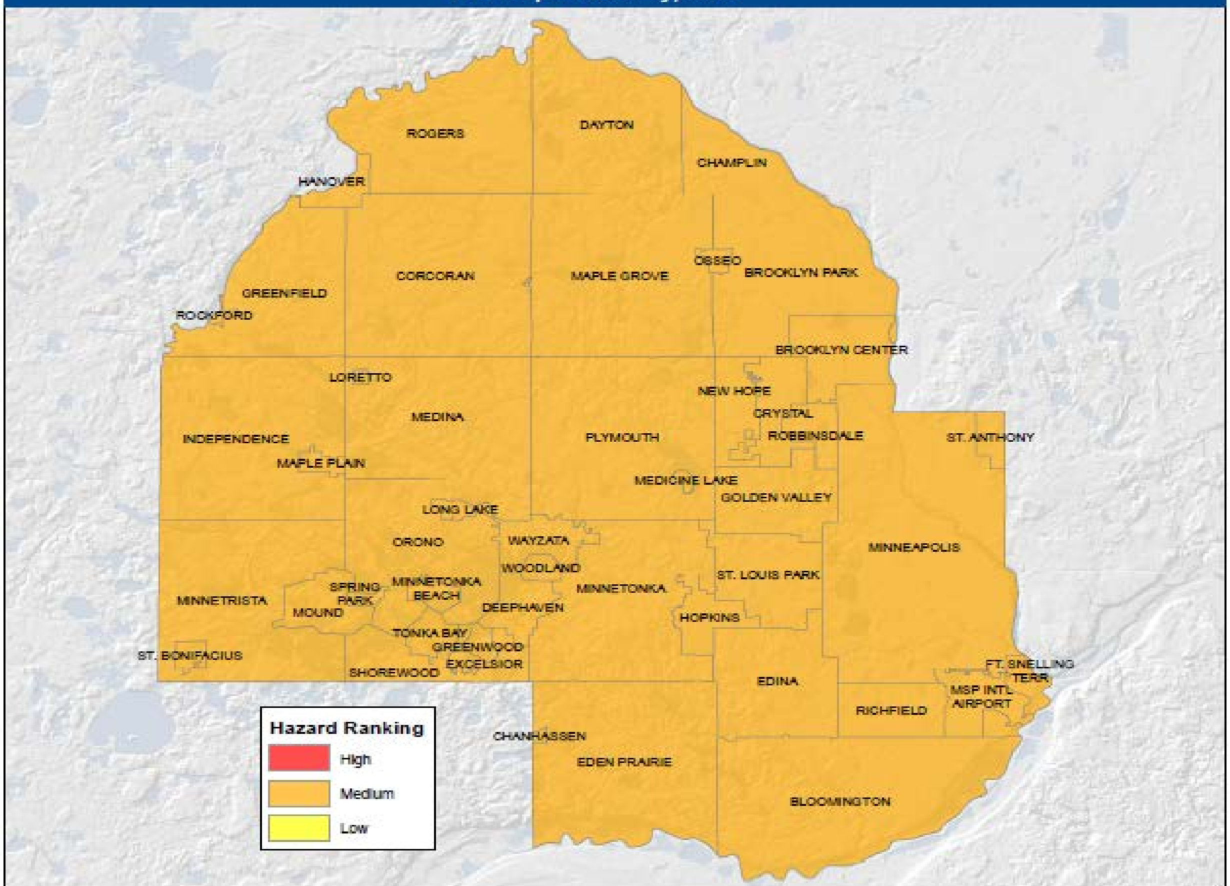
Hennepin County Emergency Management

GRAPHIC 8.1O Ice Storm

Ice Storm Hazard Ranking
Hennepin County, MN



Hazard Ranking Justification

Impacts, future predictions, and occurrences were the primary methods used to rank Ice Storms as a hazard across Hennepin County. There have not been any ice storms within Hennepin County in the past 10 years. However, the wide variety and costly impacts are the driving reasons behind ranking this hazard as medium across the county. In addition, future predictions are showing Hennepin County could be at greater risk than ever before for ice storms based on a warming climate.

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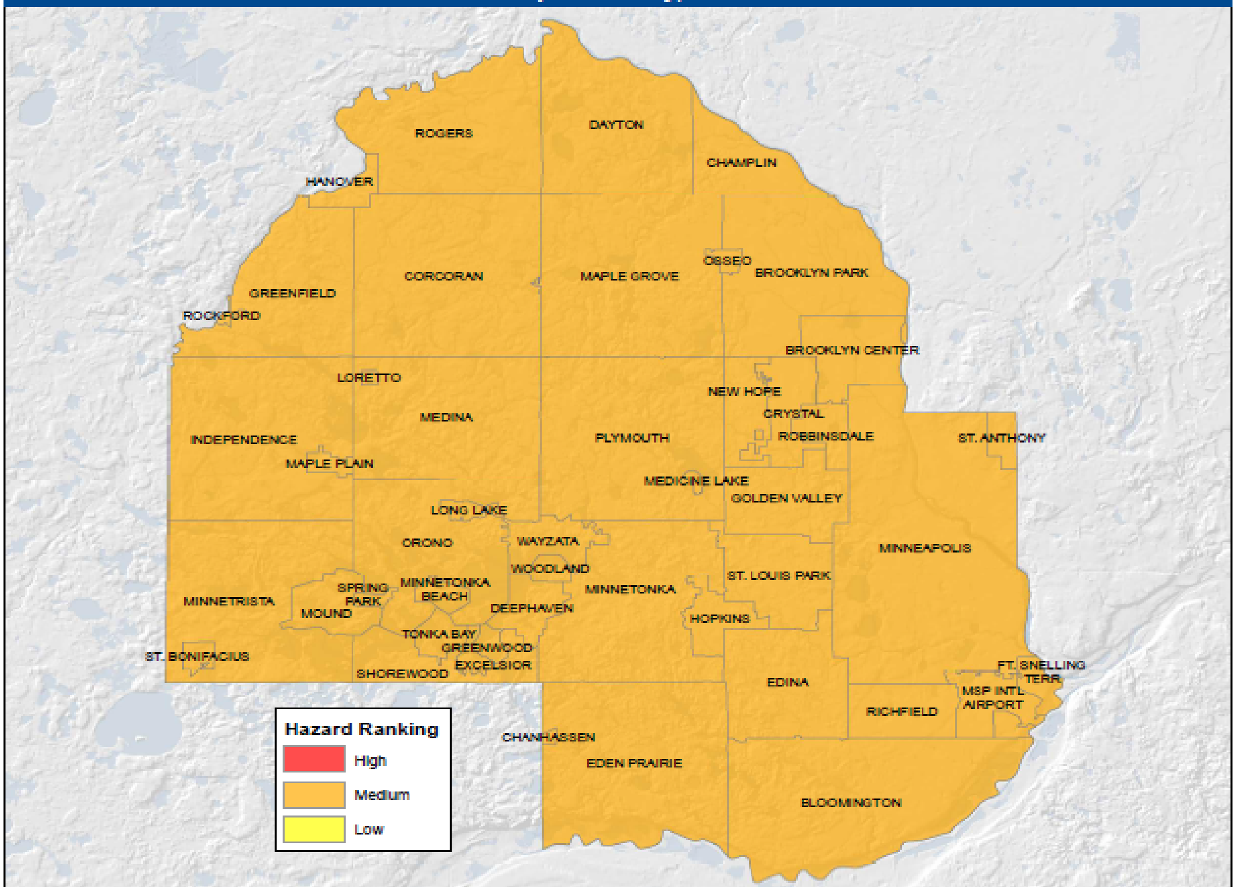
Publication date: 11/4/2016

Hennepin County Emergency Management

GRAPHIC 8.1P Lightning

Lightning Hazard Ranking
Hennepin County, MN



Hazard Ranking Justification

Occurrence and impacts were the primary methods used to rank Lightning as a hazard across Hennepin County. Lightning occurs with every single thunderstorm, and Hennepin County receives an abundance of thunderstorms every year. While magnitude of lightning is variable from storm to storm, nationwide it poses great cost every single year as well as millions of dollars' worth of damage in Hennepin County each year. Lighting is also one of the leading causes of deaths among the natural hazards each year across the nation.

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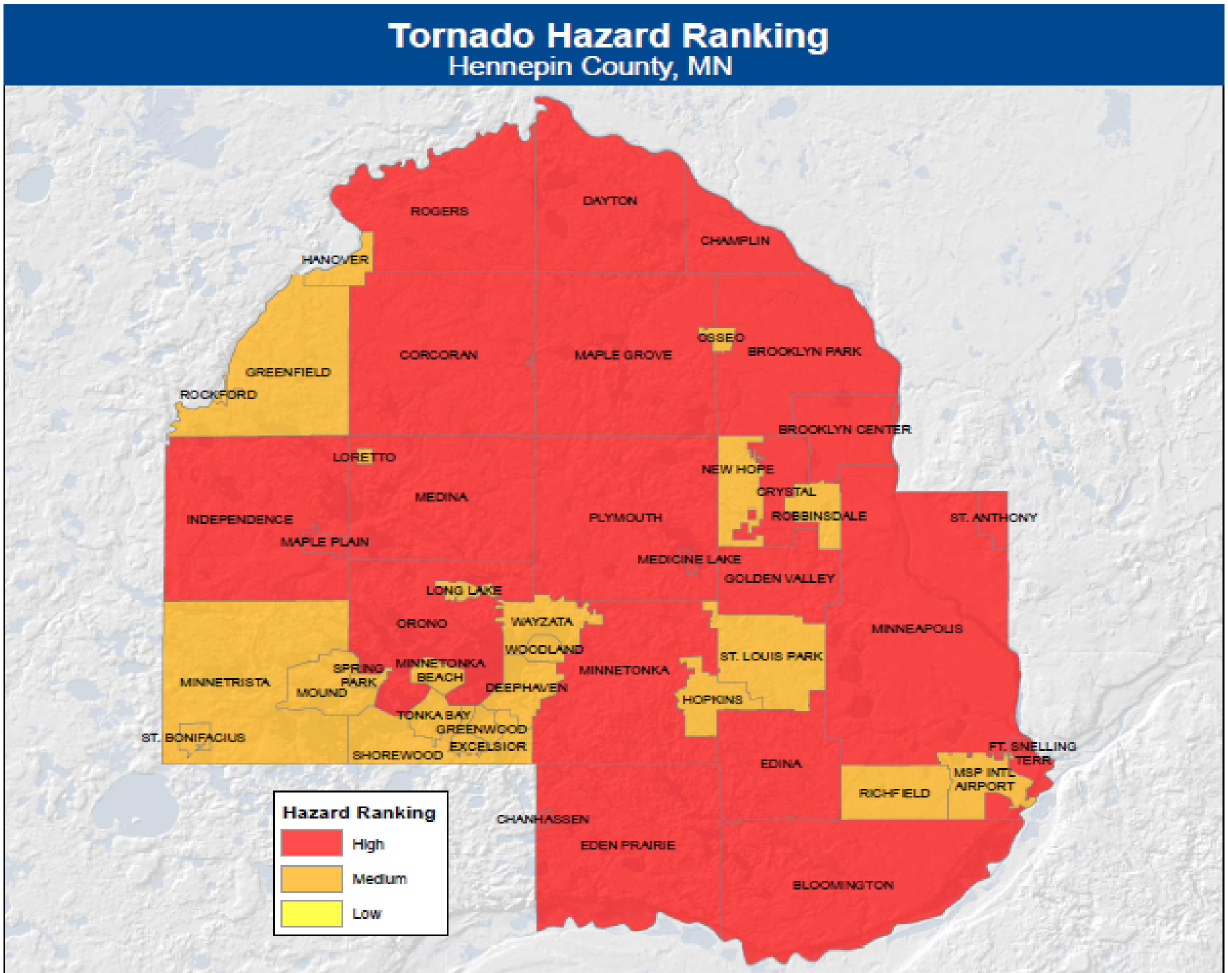
GRAPHIC 8.1Q Tornado



Hazard Ranking Justification

Occurrences, historical data, impacts, and size of city were the primary methods used to rank Tornadoes as a hazard across Hennepin County. Tornadoes do not occur every year within Hennepin County. However meteorologically, the chances of tornadoes occurring within Hennepin County are possible every single year, and with high impacts and a variety of consequences possible, the baseline ranking was medium for this hazard. Historical data was used to find cities that had more than one tornado occur within city limits, with at least one of those being greater than an F/EF 2. These cities were ranked as high. Additionally, if a city had more than three F/EF1 tornadoes in history, there were also ranked as high. Lastly, city size was looked at. While meteorologically the chances are the same for any city to be affected by a tornado, cities that have less surface area, are not as likely to see a tornado within their city limits simply because there is less area for a tornado to hit.

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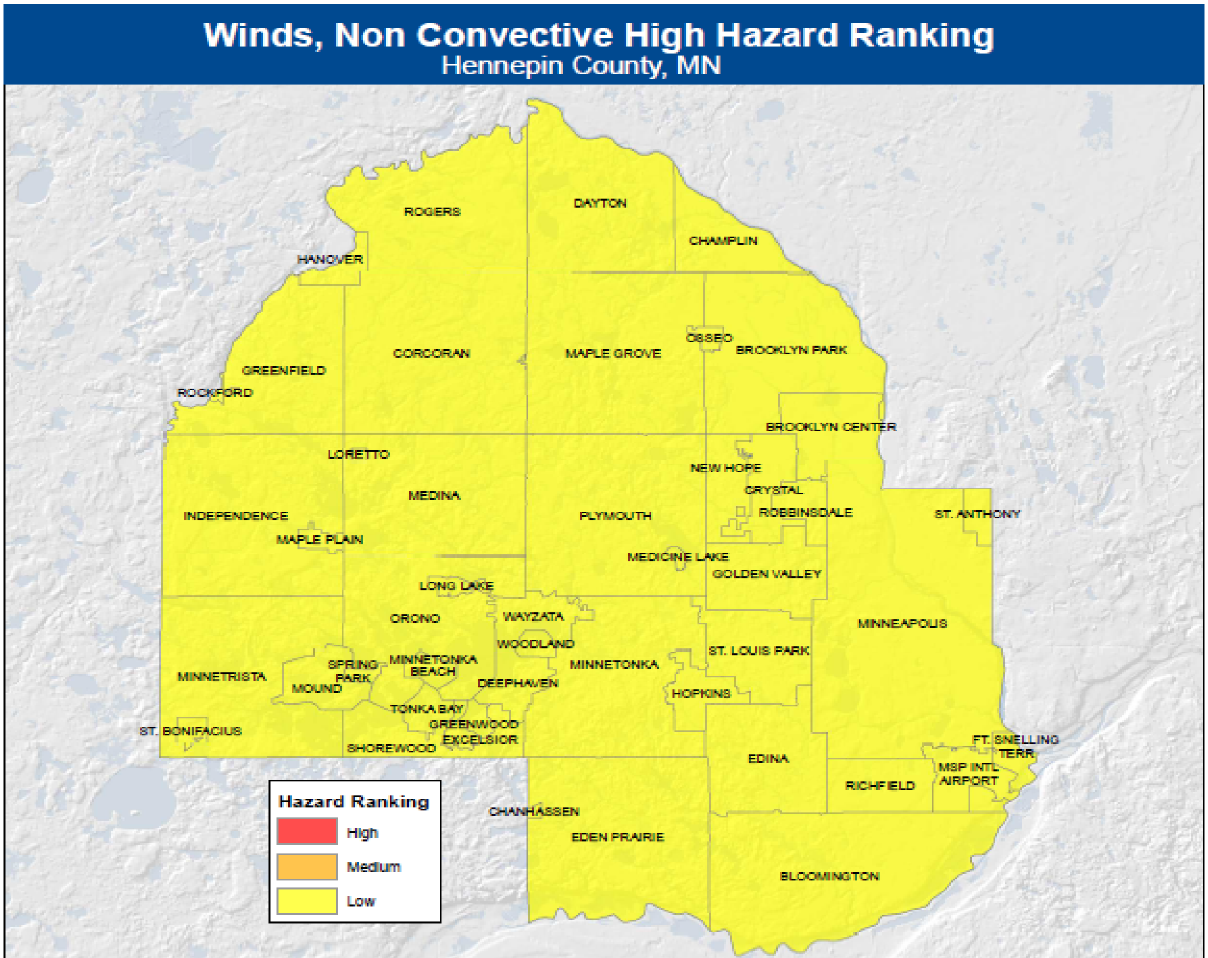
Hennepin

GRAPHIC 8.1R Winds, Non Convective High



Hazard Ranking Justification

Occurrences and future predictions were the primary methods used to rank Non-Convective High Winds as a hazard across Hennepin County. Non-convective high wind storms do not occur every year within Hennepin County, in fact, the occurring typically on a 1-3 times per year within the State of Minnesota. While these high winds can cause damage and impacts, they are typically not as severe as derechos or straight-line winds storms and are much more rate. In addition, the frequency of these storms in not directly tied to other aspects of systems they are associated with, so one is not able to say whether they will increase or decrease in the future.

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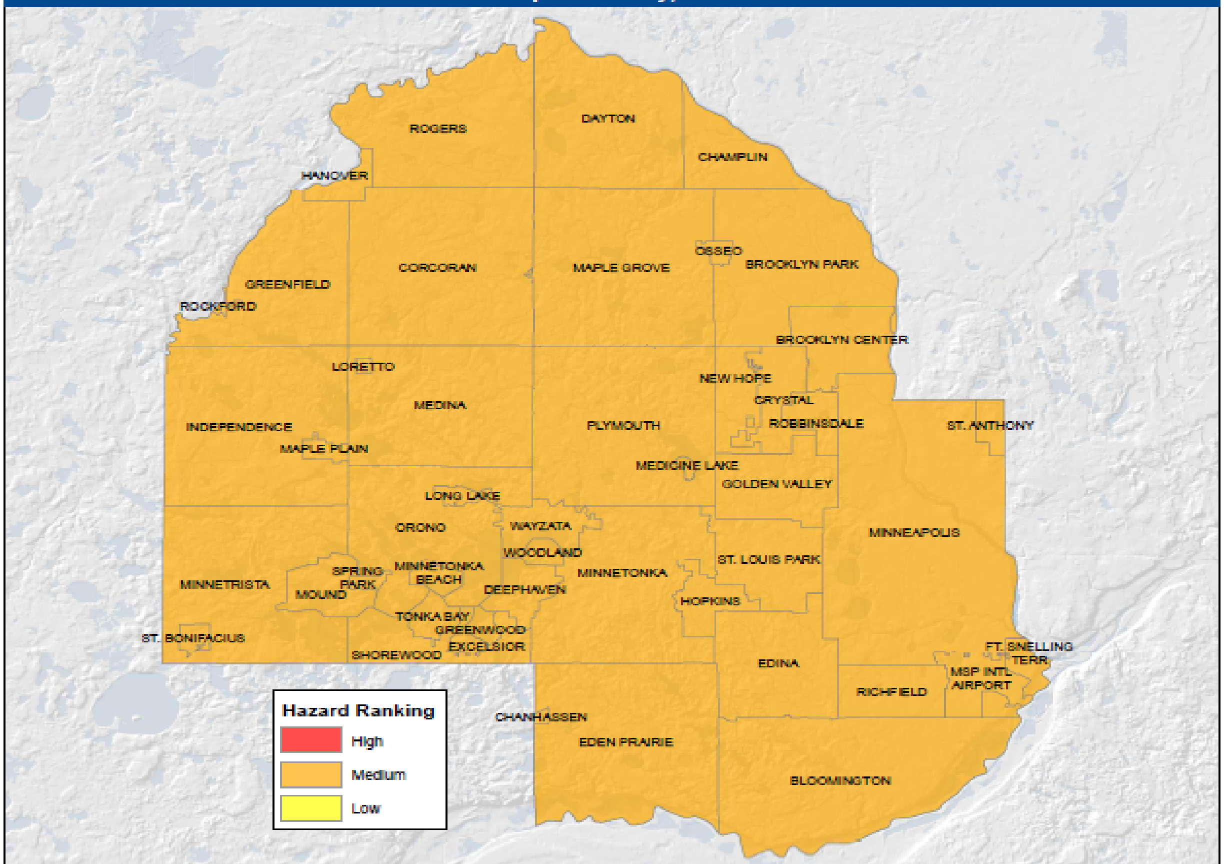
GRAPHIC 8.1S Winds, Straight-Line

Winds, Straight-Line Hazard Ranking
Hennepin County, MN



Hazard Ranking Justification

Occurrence, impacts, and area of coverage were the primary methods used to rank Extreme Straight-Line Winds as a hazard across Hennepin County. Hennepin County does not see extreme straight-line winds or derechos every single year, but they are common enough in the upper Midwest for the possibility of these winds storms occurring each year. In addition, the wide variety of impacts and consequences, as well as the large area which can be affected area reasons this hazard is ranked medium across the entire county. Not one city or more or less prone to receiving this types of storms.

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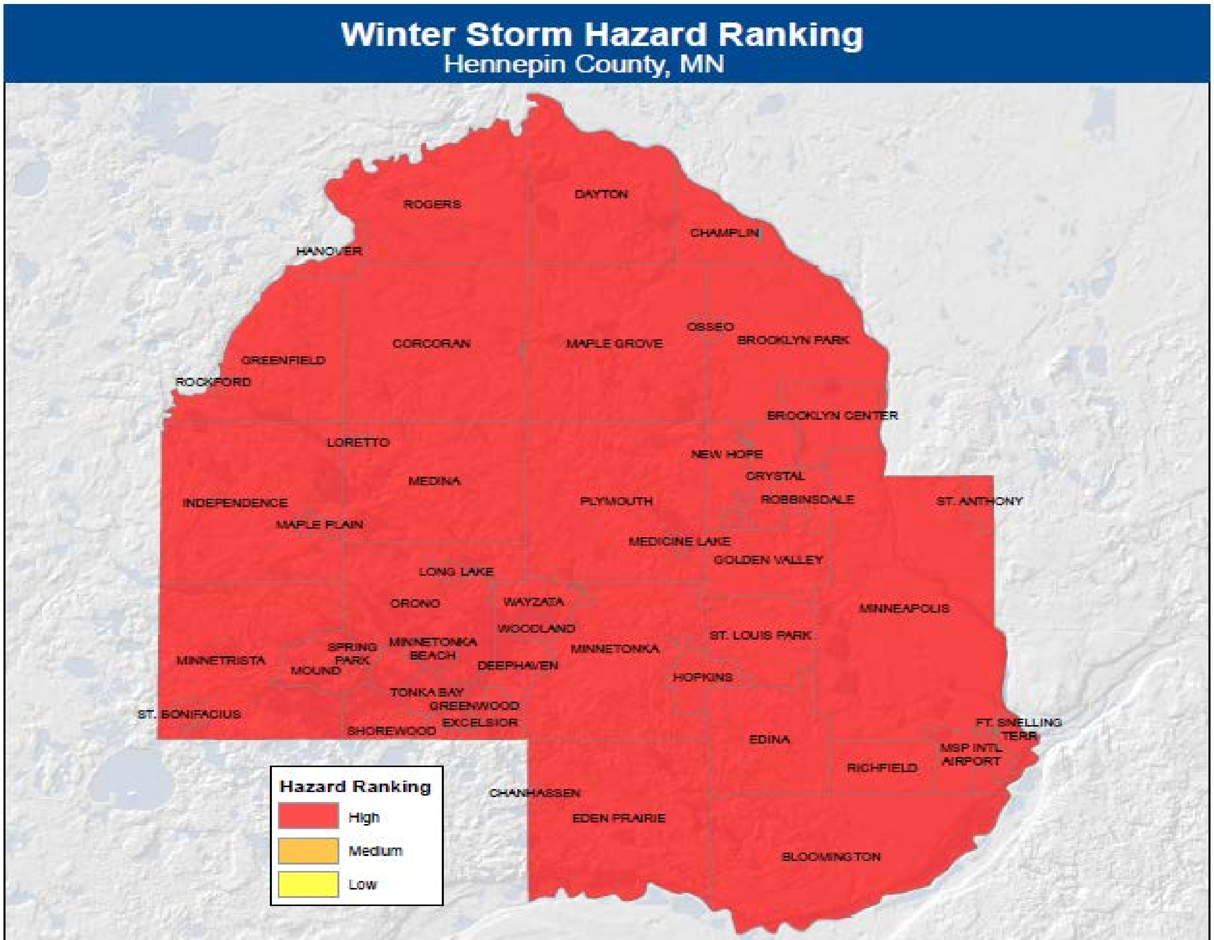
GRAPHIC 8.1T Winter Storm



Hazard Ranking Justification

Occurrences, impacts, and historical data were the primary methods used to rank Winter Storms as a hazard across Hennepin County. Every single year there are winter storm warnings with Hennepin County where we see greater than six inches of snow within 12 hours and many times greater than 8 inches within 24 hours. This does not just occur once a year/season, but multiple times within the winter season. Even though Minnesota has adapted to the needs of moving snow, the impacts and cascading consequences of winter storms along with their year occurrence result in a high ranking for this hazard.

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SECTION 9	Cultural Resources Inventory

9.1. Inventories

The effects of a disaster can be wide-ranging from human casualty to property damage to the disruption of governmental, social and economic activity. Often not considered, is the potential devastating effects of disasters on historic properties and cultural resources. Historic buildings and structures, artwork, monuments, family heirlooms, and historic documents are often irreplaceable, and may be lost forever in a disaster if not considered in the mitigation planning process. The loss of these resources is all the more painful and ironic considering how often residents rely on their presence after a disaster to reinforce connections with neighbors and the larger community, and to seek comfort in the aftermath of a disaster.

To inventory the county's cultural resources, the Steering Committee collected information from the following sources:

- National Register of Historic Places
- Minnesota's National Historic Landmarks

9.2. National Register of Historic Places- Hennepin County

It should be noted that these lists may not be complete, as they may not include those currently in the nomination process and note yet listed. **TABLE 9.2A** provides registered historical sites, please go to the National Register of Historic Places website for additional information

TABLE 9.2A Registered Historical Sites

National Register of Historic Places – Hennepin County	
Advanced Thresher /Emerson – Newton Implement Company City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924	**Ames-Florida House** City: Rockford Historic Significance: Architecture/Engineering Period of Significance: 1856
Anoka-Champlin Mississippi River Bridge City: Champlin Historic Significance: Commerce/Engineering Period of Significance: 1925-1949	**Architects and Engineers Building** City: Minneapolis Historic Significance: Commerce/Engineering Period of Significance: 1900-1924
Atwater, Isaac, House City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899, 1850-1874	**Baird, George W., House** City: Edina Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899
Bardwell-Ferrant House City: Minneapolis	**Barry, Margaret, Settlement House** City: Minneapolis

Historic Significance: Architecture/Engineering Period of Significance: 1875-1899	Historic Significance: Education/Social History Period of Significance: 1900-1924
Bartholomew, Riley Lucas, House City: Richfield Historic Significance: Person Period of Significance: 1875-1899, 1850-1874	**Basilica of St. Mary Catholic** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924
Bennett-McBride House City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924	**Bovey, Charles Cranston & Kate Koon, House** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924
Bremer, Frederika, Intermediate School City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899	**Burwell, Charles H., House** City: Minnetonka Historic Significance: Architecture/Engineering Period of Significance: 1875-1899, 1850-1874
Butler Brothers Company City: Minneapolis Historic Significance: Architecture Period of Significance: 1900-1924	**Cahill School** City: Edina Historic Significance: Person Period of Significance: 1925-1949, 1900-1924, 1875-1899, 1850-1874
Calhoun Beach Club City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949	**Cappelen Memorial Bridge** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924
Carpenter, Elbert L., House City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924	**Carpenter, Eugene J., House** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924
Cedar Avenue Bridge City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949	**Chadwick, Loren L., Cottages** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924
Chamber of Commerce City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924	**Chamber of Commerce Building** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924
Chicago, Milwaukee & St. Paul Railroad Grade Separation City: Minneapolis Historic Significance: Event Period of Significance: 1900-1924	**Chicago, Milwaukee, St. Paul & Pacific Depot** City: Saint Louis Park Historic Significance: Event Period of Significance: 1925-1949, 1900-1924, 1875-1899
Chicago, Milwaukee, St. Paul & Pacific Depot, Freight House & Train Shed	**Christ Church Lutheran** City: Minneapolis

City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899	Historic Significance: Architecture/Engineering Period of Significance: 1925-1949
Church of St. Stephen (Catholic) City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949	**Coe, Amos B., House** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899
Como-Harriet Streetcar Line & Trolley City: Minneapolis Historic Significance: Event Period of Significance: 1925-1949, 1900-1924, 1875-1899	**Country Club Historic District** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924
Crane Island Historic District City: Minnestrista Historic Significance: Event Period of Significance: 1925-1949, 1900-1924	**Cummins, John R., Farmhouse** City: Eden Prairie Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899
Cutter, B.O., House City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1850-1874	**Dania Hall** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899
East Lake Branch Library City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924	**Edina Mills** City: Edina Historic Significance: NA Period of Significance: NA
Eitel Hospital City: Minneapolis Historic Significance: Event, Person Period of Significance: 1925-1949, 1900-1924	**Excelsior Fruit Growers Association Building** City: Excelsior Historic Significance: Agriculture, Commerce Period of Significance: 1925-1949, 1900-1924
Excelsior Public School City: Excelsior Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899	**Farmers & Mechanics Savings Bank** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1950-1974, 1925, 1949
Farmers & Mechanics Savings Bank City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899	**Fire Station No. 19** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899
First Church of Christ Scientist City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899	**First Congregational Church** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899
First National Bank – Soo Line Building City: Minneapolis Historic Significance: Architecture/Engineering	**Fisk, Woodbury, House** City: Minneapolis Historic Significance: Architecture/Engineering

Period of Significance: 1950-1974, 1925-1949, 1900-1924	Period of Significance: 1850-1874
Flour Exchange Building City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899	**Fort Snelling** City: Minneapolis Historic Significance: Event Period of Significance: 1900-1924, 1875-1899, 1850-1874, 1825-1849, 1800-1824
Fort Snelling – Mendota Bridge City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949	**Forum Cafeteria** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949
Foshay Tower City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949	**Fournier, Lawrence A. & Mary, House** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924
Fowler Methodist Episcopal Church City: Minneapolis Historic Significance: Architecture/Social History Period of Significance: 1900-1924, 1875-1899	**Franklin Branch Library** City: Minneapolis Historic Significance: Event/Person Period of Significance: 1900-1924
Gethsemane Episcopal Church City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924	**Gideon, Peter, Farmhouse** City: Shorewood Historic Significance: Person Period of Significance: 1875-1899, 1850-1874
Glen Lake Children's Camp City: Eden Prairie Historic Significance: Health/Medicine Period of Significance: 1925-1949	**Gluek, John G, & Minnie, House & Carriage House** City: Shorewood Historic Significance: Architecture/Engineering Period of Significance: 1900-1924
Grace Evangelical Lutheran Church City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924	**Great Northern Implement Company** City: Wayzata Historic Significance: Architecture/Engineering Period of Significance: 1925-1950, 1900-1924
Grimes, Jonathan Taylor, house City: Edina Historic Significance: Architecture/Engineering Period of Significance: 1875-1899, 1850-1874	**Hagel Family Farm** City: Rogers Historic Significance: Architecture/Engineering Period of Significance: 1950-1974, 1925-1949, 1900-1924, 1875-1899, 1850, 1874
Handicraft Guild Building City: Minneapolis Historic Significance: Event Period of Significance: 1925-1949, 1900-1924	**Hanover Bridge** City: Rogers Historic Significance: Architecture/Engineering Period of Significance: 1875-1899
Healy Block Residential Historic District	**Hennepin County Library**

City: Minneapolis Historic Significance: Event Period of Significance: 1875-1899	City: Robbinsdale Historic Significance: Event Period of Significance: 1925-1949
Hennepin Theater City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924	**Hewitt, Edwin, H., House** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924
Hinkle-Murphy House City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899	**Holmes, Henry E., House** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899
Intercity Bridge City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949	**Interlachen Bridge (Ford Bridge)** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924
Interlachen Bridge (Cottage City Bridge) City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924	**Jones, Harry W., House** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-2949, 1900-1924, 1875-1899
Lakewood Cemetery Memorial Chapel City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924	**Legg, Harry F., House** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899
Linden Hills Branch Library City: Minneapolis Historic Significance: Event/Person Period of Significance: 1925-1949	**Little Sister of the Poor Home for Aged** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899
Lock and Dam No. 2 City: Minneapolis Historic Significance: Event Period of Significance: 1900-1924, 1875-1899	**Lohmar, John, House** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899
Lumber Exchange Building City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899	**Madison School** City: Minneapolis Historic Significance: NA Period of Significance: NA
Martin, Charles J., House City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924	**Masonic Temple** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899
Maternity Hospital City: Minneapolis	**Milwaukee Ave Historic District** City: Minneapolis

Historic Significance: Person Period of Significance: 190-1924	Historic Significance: Architecture/Engineering Period of Significance: 1875-1899
Minneapolis Armory City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949	**Minneapolis Brewing Company** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924, 1875-1899
Minneapolis City Hall-Hennepin County Courthouse City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899	**Minneapolis Fire Department Repair Shop** City: Minneapolis Historic Significance: Event Period of Significance: 1925-1949, 1900-1924
Minneapolis Pioneers & Soldiers Memorial Cemetery City: Minneapolis Historic Significance: Event Period of Significance: 1925-1949	**Minneapolis Public Library, North Branch** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899
Minneapolis Warehouse Historic District City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924, 1875-1899, 1850-1874	**Minneapolis YMCA Central Building** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924
Minnehaha Grange Hall City: Edina Historic Significance: Architecture/Engineering Period of Significance: 1875-1899. 1850-1874	**Minnehaha Historic District** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899, 1850-1874, 1825-1849
Minnesota Soldiers' Home Historic District City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 192-1949, 1900-1924. 1875-1899	**Minnetonka Town Hall** City: Minnetonka Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924
Moline, Milburn & Stoddard Company City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899	**Morse Jr., Elisha & Lizzie, House** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1850-1874
Neils, Frieda & Henry J., House City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1950-1974	**New Century Mill (Boundary Increase)** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899
New Century Mill (Boundary Decrease) City: Minneapolis Historic Significance: Architecture/Engineering	**New Century Mill (Boundary Increase)** City: Minneapolis Historic Significance: Architecture/Engineering

Period of Significance: 1900-1924, 1875-1899	Period of Significance: 1900-1924, 1875-1899
New Main – Augsburg Seminary City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924	**Newell, George R., House** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899
Nicollet Hotel City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924	**Nokomis Knoll Residential Historic District** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924
North East Neighborhood House City: Minneapolis Historic Significance: Event Period of Significance: 1950-1974, 1925-1949, 1900-1924	**Northwestern Bell Telephone Company Building** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949
Northwestern Knitting Company Factory City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924	**Ogden Apartment Hotel** City: Minneapolis Historic Significance: Event Period of Significance: 1925-1949, 1900-1924
Old Log Theater City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924	**Owre, Dr. Oscar, house** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924
Parker, Charles & Grace, House City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924	**Peavey-Haglin experimental Concrete Grain Elevator** City: Saint Louis Park Historic Significance: Architecture/Engineering Period of Significance: 1875-1899
Pence Automobile Company Building City: Minneapolis Historic Significance: Event/Person Period of Significance: 1925-1949, 1900-1924	**Phi Gamma Delta Fraternity House** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924
Pillsbury A Mill City: Minneapolis Historic Significance: Event Period of Significance: 1875-1899	**Pioneer Steel Elevator** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899
Pond, Gideon H., House City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899	**Prescott House** City: Minneapolis Historic Significance: Person Period of Significance: 1850-1874
Prospect Park Water Tower & Tower Hill Park City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924	**Purcell, William Gray, House** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924

Queene Avenue Bridge City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924	**Rand Tower** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949
Roosevelt Branch Library City: Minneapolis Historic Significance: Person Period of Significance: 1924-1949	**Sanford, Maria, House** City: Minneapolis Historic Significance: Person Period of Significance: 1900-1924
Sears, Roebuck & Company Mail-Order Warehouse & Retail Store City: Minneapolis Historic Significance: Event Period of Significance: 1950-1974, 1925-1949	**Second Church of Christ, Scientist, Administration Building** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949
Semple, Anne C & Brank B., House City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924	**Shubert, Same S., Theater** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924
Smith, H. Alden, House City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899	**Smith, Leno O., House** City: Minneapolis Historic Significance: Person Period of Significance: 1925-1949
South Ninth Street Historic District City: Minneapolis Historic Significance: NA Period of Significance: NA	**St. Anthony Falls Historic District** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924, 1875-1899, 1850-1874, 1825-1849
State Theater City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924	**Station 13 Minneapolis Fire Department** City: Minneapolis Historic Significance: Event Period of Significance: 1900-1924
Station 28 Minneapolis Fire Department City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924	**Stevens Square Historic District** City: Minneapolis Historic Significance: Event Period of Significance: 1925-1949, 1900-1924
Stewart Memorial Presbyterian Church City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1925	**Summer Branch Library** City: Minneapolis Historic Significance: Person/Event Period of Significance: 1925-1949, 1900-1924
Swinford Townhouses & Apartments City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899	**Thirty-Sixth Street Branch Library** City: Minneapolis Historic Significance: Event/Person Period of Significance: 1925-1949, 1900-1924

Thompson Summer House City: Minnetonka Beach Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924, 1875-1899	**Turnblad, Sawn, House** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949, 1900-1924
Twin City Rapid Transit Company Steam Power Plant City: Minneapolis Historic Significance: Event Period of Significance: 1925-1949, 1900-1924	**United States Post Office** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924
University of Minnesota Old Campus Historic District City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899	**Van Cleve, Horatio P., House** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899, 1850-1874
Van Dusen, George W & Nancy B., House City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899	**Walker Branch Library** City: Minneapolis Historic Significance: Event/Person Period of Significance: 1925-1949, 1900-1924
Washburn A Mill Complex City: Minneapolis Historic Significance: Event Period of Significance: 1900-1924, 1875-1899	**Washburn Park Water Tower** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949
Washburn – Fair Oaks Mansion District City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1900-1924, 1875-1899	**Wesley Methodist Episcopal Church** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1875-1899
Westminster Presbyterian Church City: Minneapolis Historic Significance: Event Period of Significance: 1925-1949, 1900-1924, 1875-1899	**White Castle Building No. 8** City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949
Wiley, Malcolm., House City: Minneapolis Historic Significance: Architecture/Engineering Period of Significance: 1925-1949	**Wirth, Theodore, House – Administration Building** City: Minneapolis Historic Significance: Person Period of Significance: 1925-1949, 1900-1925
Wyer, Allemarinda & James, House City: Excelsior Historic Significance: Architecture/Engineering Period of Significance: 1875-1899	

9.3. Hennepin County Historic Landmark Maps

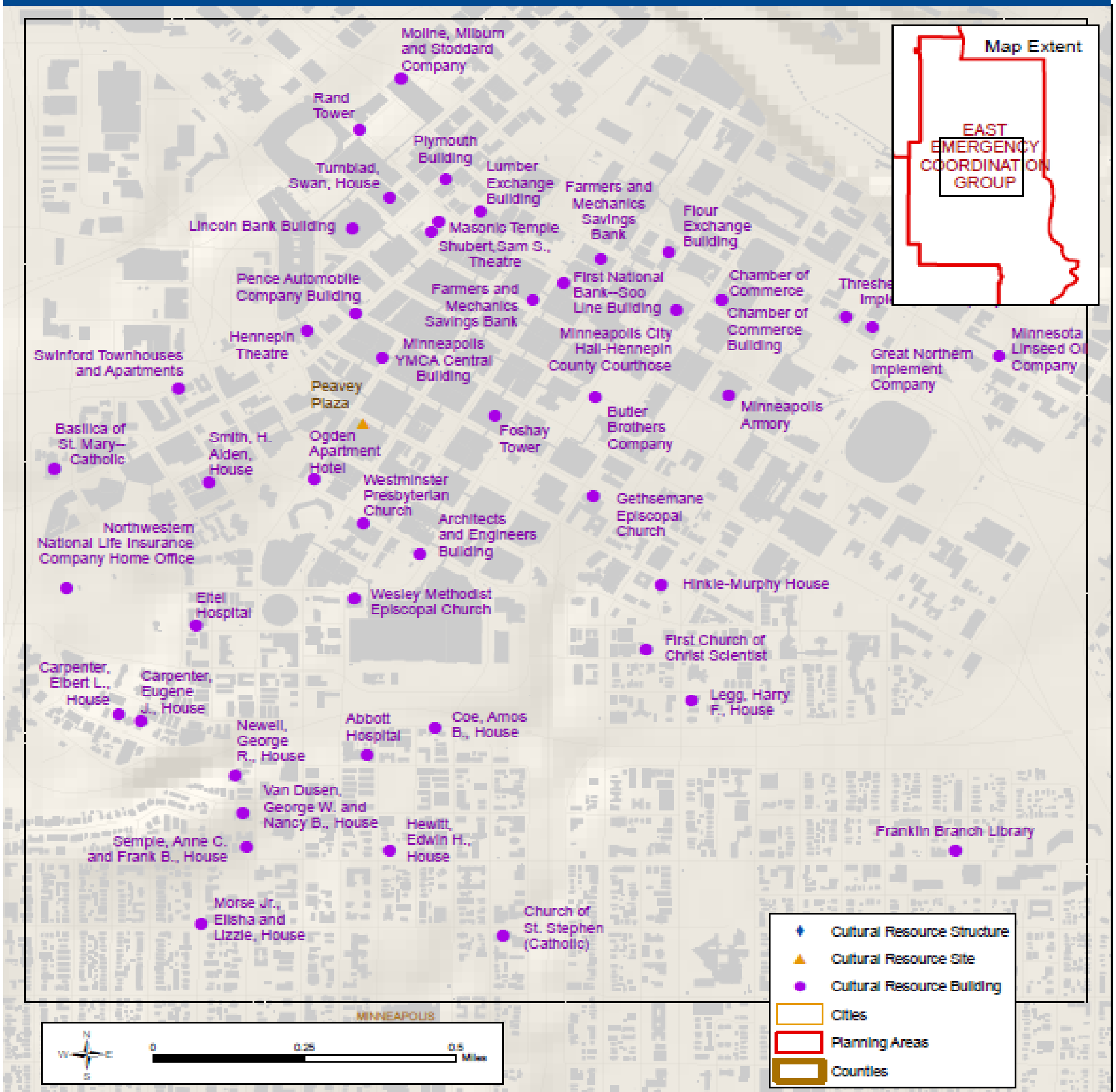
National Historic Landmarks (NHLs) are historic places that possess exceptional value in commemorating or illustrating the history of the United States. The National Park Service's National Historic Landmarks Program oversees the designation of such sites. The following Hennepin County sites were designated by the United States Secretary of the Interior because they met one of the criteria **TABLE 9.3A**:

- Sites where events of national historic significance occurred;
- Places where prominent persons lived or worked;
- Icons of ideas that shaped the nation;
- Outstanding examples of design or construction;
- Places characterizing a way of life or;
- Archeological sites able to yield information.

TABLE 9.3A Minnesota's National Historic Landmarks- Hennepin County

Minnesota's National Historic Landmarks – Hennepin County	
Landmark	Year
Christ Church Lutheran, Minneapolis	1/16/09
Fort Snelling,	12/19/60
Peavey-Haglin Experimental Concrete Grain Elevator, Saint Louis Park	12/21/81
Pillsbury A Mill, Minneapolis	11/13/66
Washburn A Mill Complex, Minneapolis	5/4/83

Nation Register Historic Places - Hennepin County 2015
Minneapolis (Downtown)



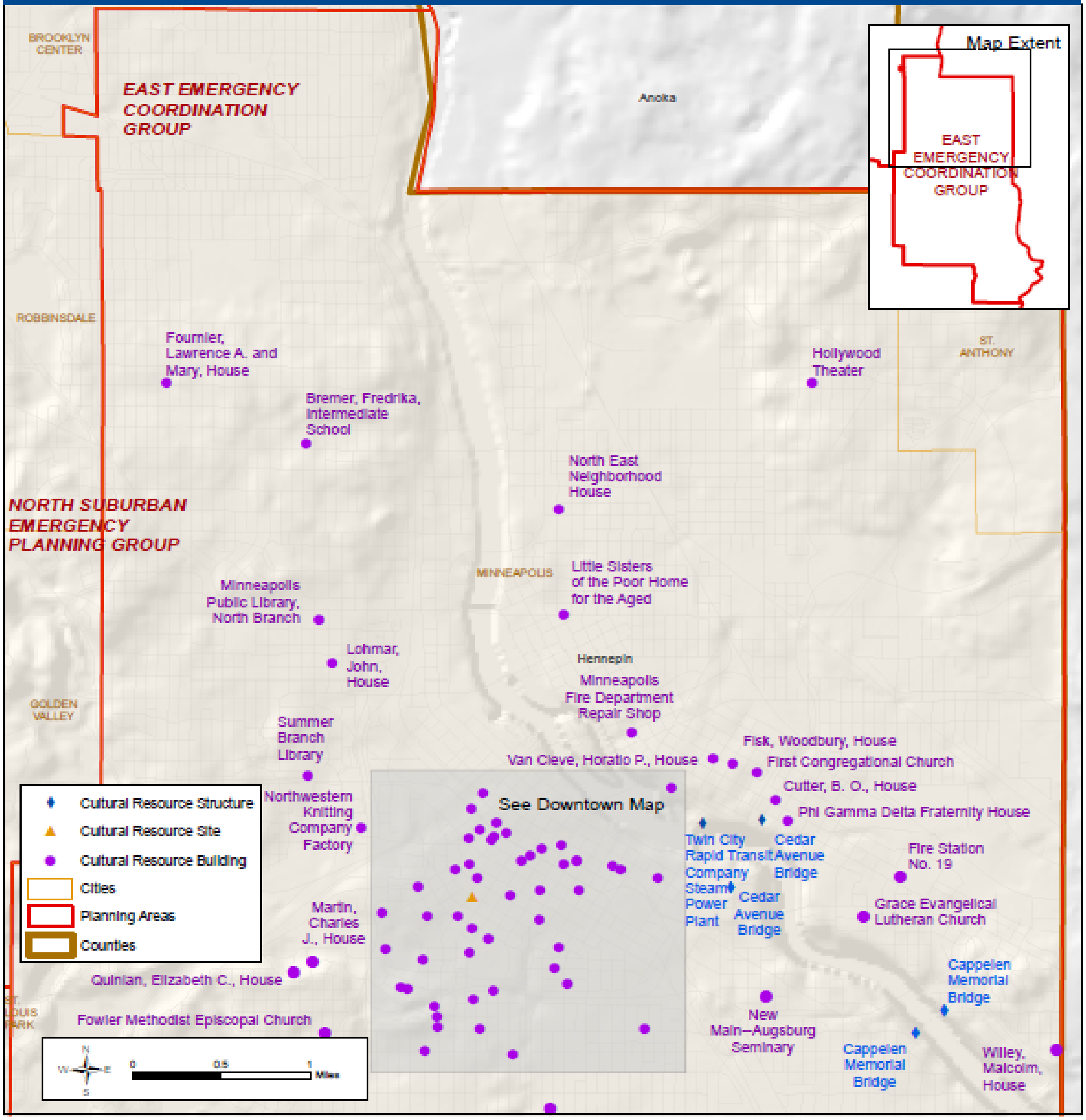
Hennepin County 2015 Mitigation Plan
Publication date: 11/4/2015

Source: National Park Service
National Register Historic Places (NHRP)
Public Dataset Spatial Data (GIS)

Hennepin County Emergency Management

Hennepin

Nation Register Historic Places - Hennepin County 2015
Minneapolis North



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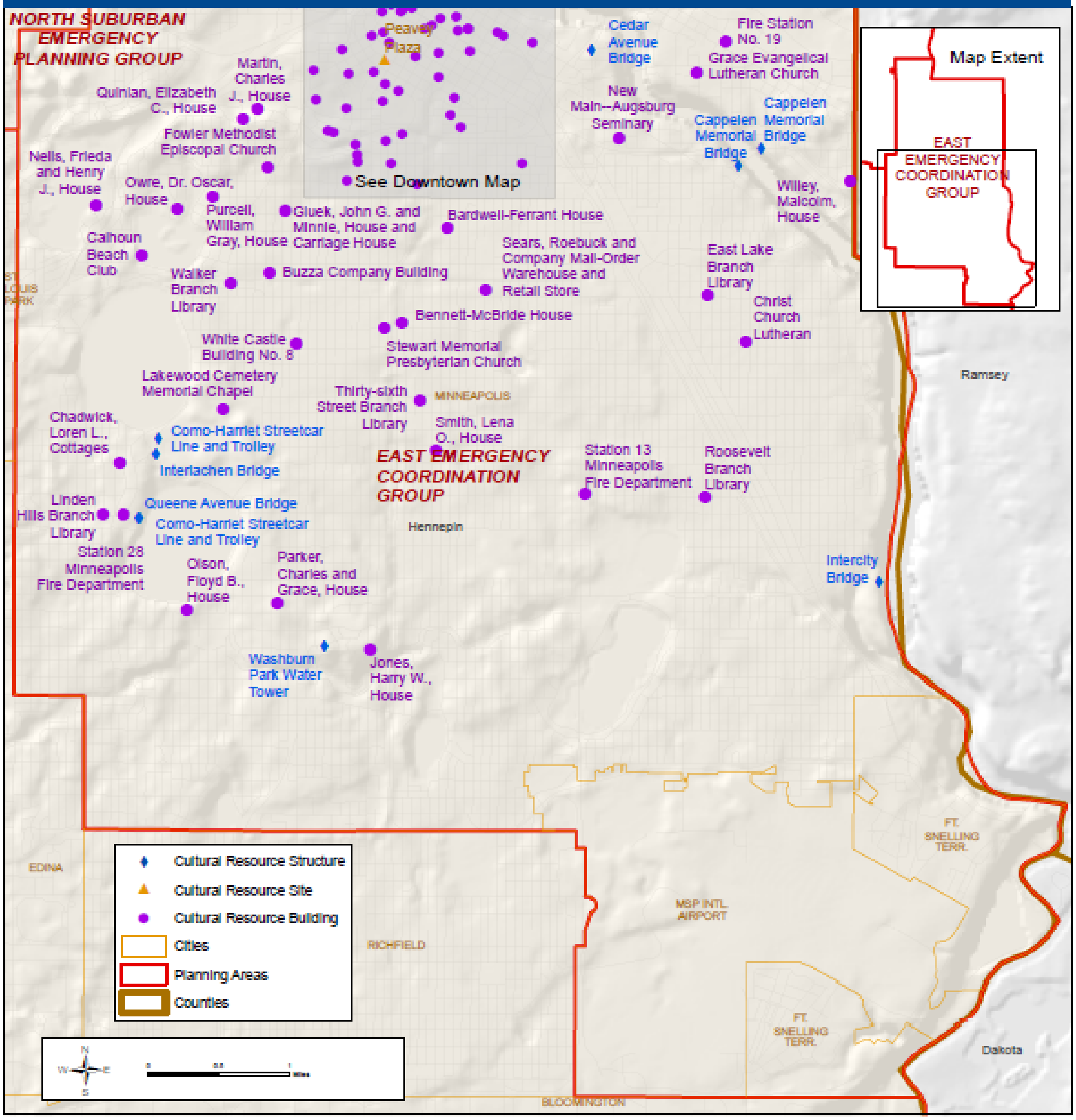
Publication date: 11/13/2015

Source: National Park Service
National Register Historic Places (NHRP)
Public Dataset Spatial Data (GIS)

Hennepin County Emergency Management

Nation Register Historic Places - Hennepin County 2015 Minneapolis South



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Publication date: 11/13/2015

Source: National Park Service
National Register Historic Places (NHRP)
Public Dataset Spatial Data (GIS)

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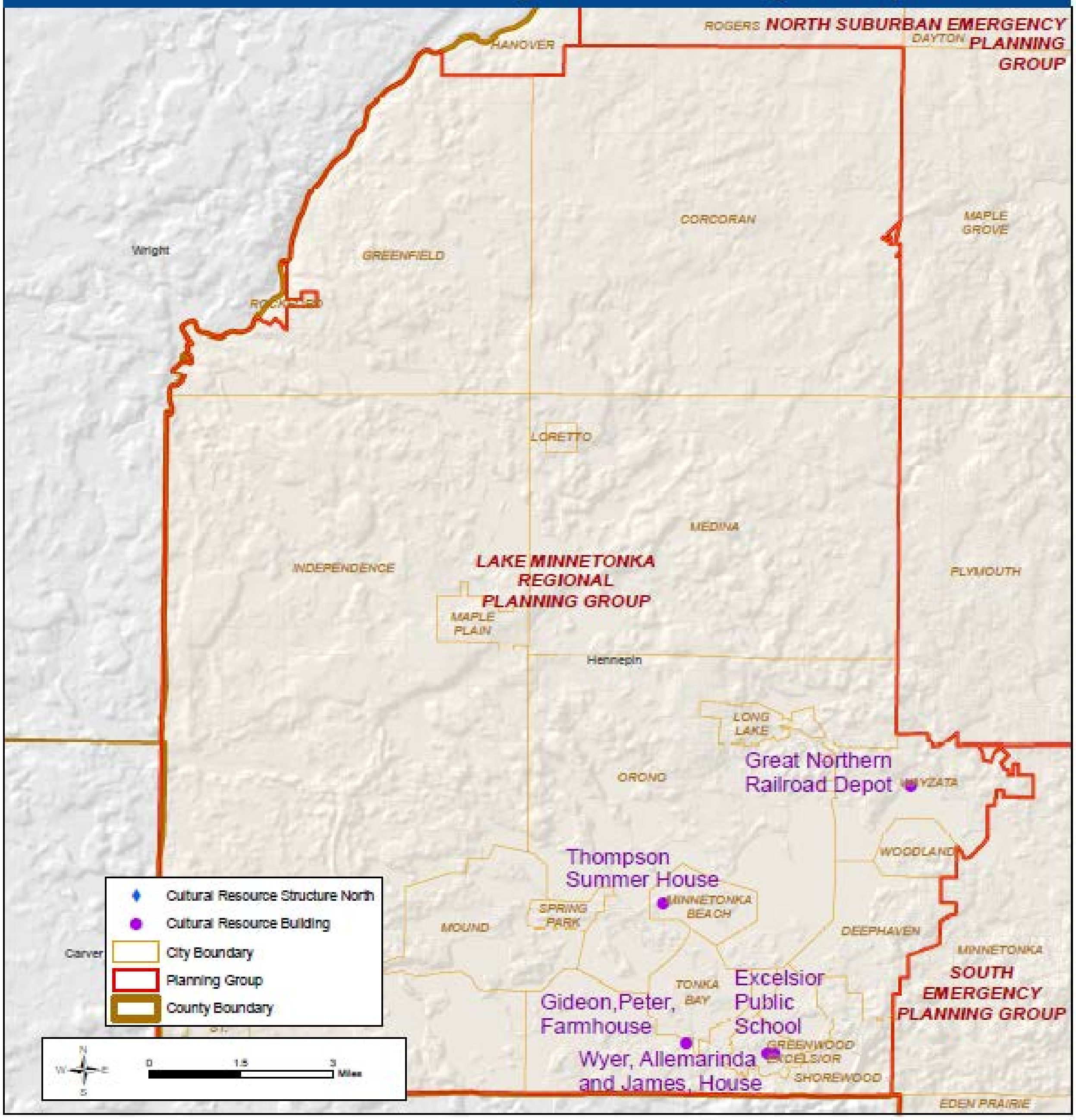
Hennepin County Emergency Management

Nation Register Historic Places - Hennepin County 2015
Lake Minnetonka Regional Planning Group



Hennepin County 2015 Mitigation Plan
Publication date: 11/2/2015
Source: National Park Service
National Register Historic Places (NHRP)
Public Dataset Spatial Data (GIS)

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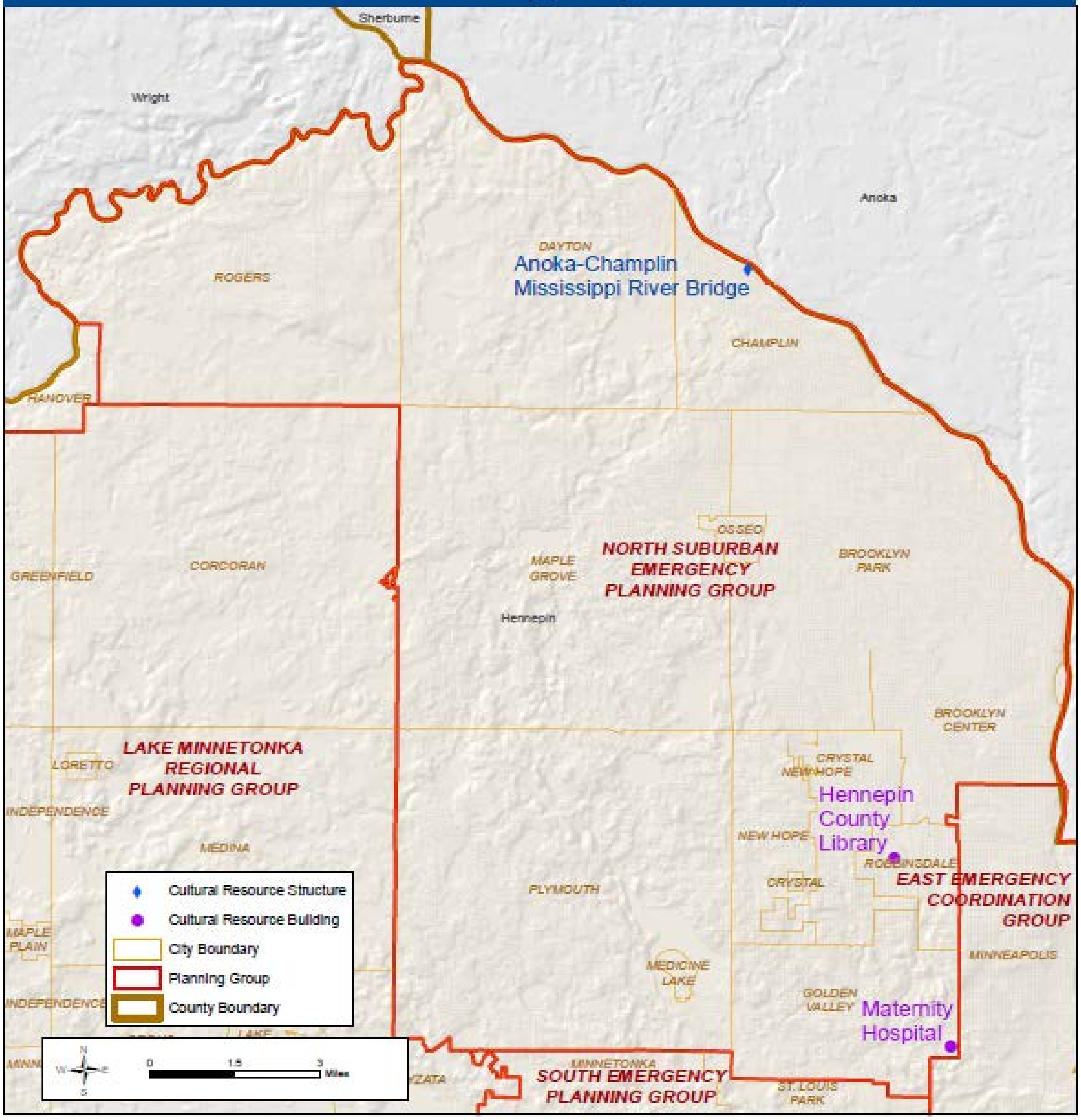
Hennepin County Emergency Management

Nation Register Historic Places - Hennepin County 2015
North Suburban Emergency Planning Group



Hennepin County 2015 Mitigation Plan
Publication date: 11/3/2015

Source: National Park Service
National Register Historic Places (NHRP)
Public Dataset Spatial Data (GIS)

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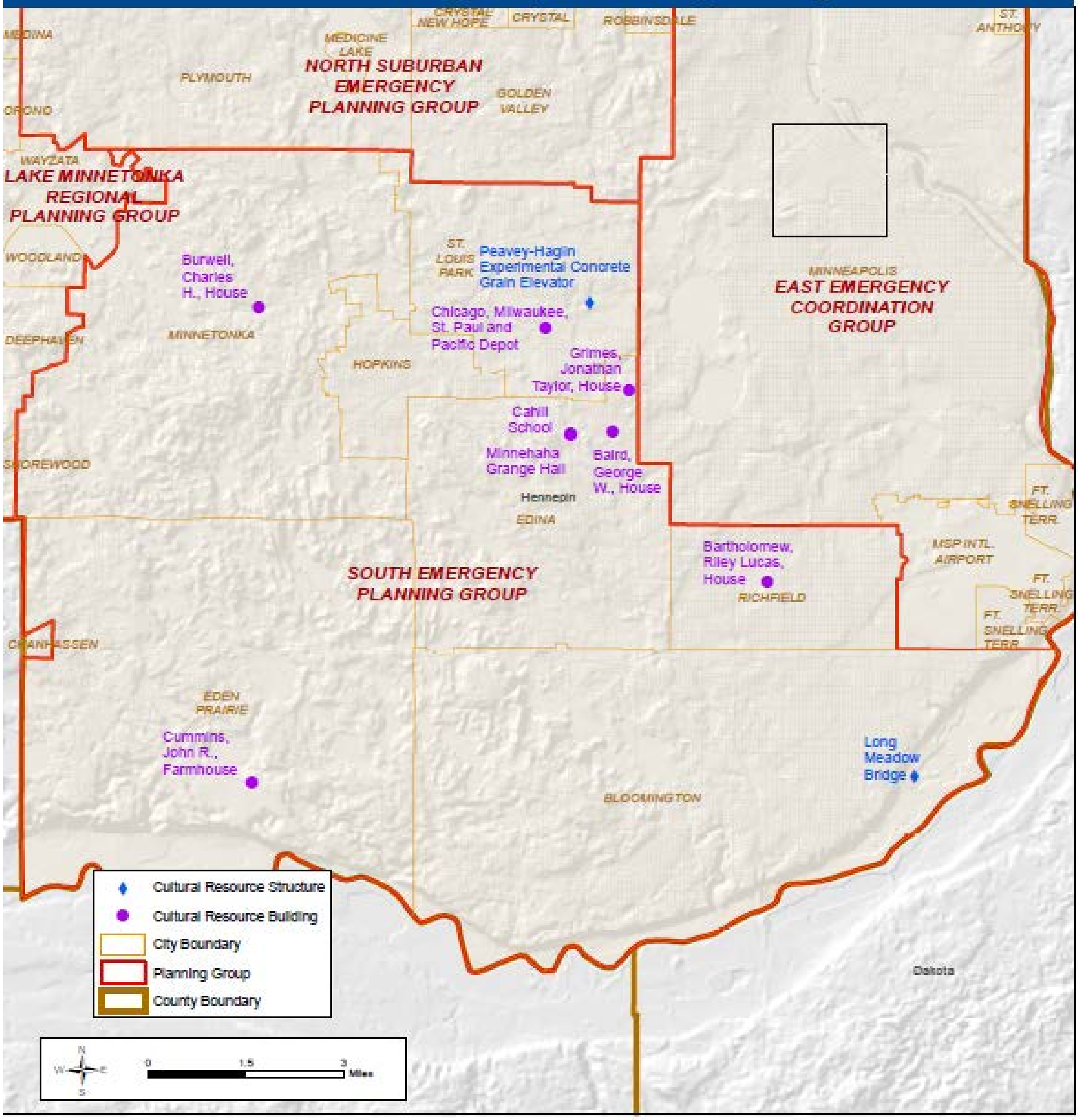
Hennepin County Emergency Management

Nation Register Historic Places - Hennepin County 2015
South Emergency Planning Group



Hennepin County 2015 Mitigation Plan
Publication date: 11/3/2015

Source: National Park Service
National Register Historic Places (NHRP)
Public Dataset Spatial Data (GIS)

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