MINNESOTA GO

Planning Minnesota's Transportation Future

CLIMATE CHANGE TREND ANALYSIS

CONTENTS

SUMMARY

Climate change is a global crisis and its effects in Minnesota have been particularly serious. The annual average temperature in the state has risen two degrees over the past century. This is 25% more than the global average. Minnesota's winter temperatures have risen more than any other state over the past 40 years. Minnesota has also experienced more large storms.[1] Many of Minnesota's diverse ecosystems are also particularly sensitive to a changing climate. Species at the edges of these ecosystems such as moose, loons and wild rice are most vulnerable to climate change and at risk of disappearing from Minnesota. These climate changes are having negative effects on the transportation system and likely to get much worse in the future.

Minnesota's transportation sector is also contributing to climate change. Transportation is the largest contributor to greenhouse gas emissions in the state. This has been the case since 2016. MnDOT committed to ambitious climate change goals in alignment with state executive orders and the Next Generation Clean Energy Act. The goal is to reduce emissions in Minnesota by 80% by 2050.[2] To do this, MnDOT committed to activities including reporting, addressing, mitigating and adapting to climate change.

CLIMATE STRESSORS AND HAZARDS

Climate change has many different impacts on the transportation system. Table 1 shows the types of impacts climate can have on the transportation sector and the confidence Minnesota will experience a change in the frequency of that impact in the coming two decades.

Table 1: Summary of Climate Impacts and Transportation Outcomes in Minnesota

Climate Impact	Confidence in Change for MN during Next 20 Years	Effect to Transportation System
Heavy Precipitation / Flooding	Very High	• Damage to highway, rail infrastructure, hydraulics infrastructure, and airport runways • Flooding over roads will slow operations and performance
Warmer Winters	Very High	• More ice build-up and freezing precipitation • Reduced pavement conditions and life cycles • Downed power lines with ice storms • Reduced ice cover on water bodies leading to greater rates of evaporation

[1] Elizabeth Dunbar and Dan Kraker, "Climate Change in Minnesota: More Heat, More Big Storms," MPR News, February 2, 2015, http://www.mprnews.org/story/2015/02/02/climate-change-the-proof.

[2] "Minnesota Session Laws – 2008, Regular Session," Office of the Revisor of Statutes, accessed June 21, 2021, https://www.revisor.mn.gov/laws/?id=287&year=2008&type=0.

Climate Impact	Confidence in Change for MN during Next 20 Years	Effect to Transportation System
New Species Geographic Ranges	High	• Changes in roadside vegetation species • Soil erosion • Increase in invasive species populations • Increased exposure of construction and maintenance crews to vector-borne diseases
Drought	Medium	• Reduced river navigability for barges • Stressed roadside vegetation reducing rainwater storage and increasing soil erosion in the long-term
High Heat	Low	• Pavement and rail buckling • Vehicles overheating • Electrical system malfunctions • Limitations on construction hours
Wildfires	Unknown	• Road closures • Immediate and significant threat to human safety • Damage to roadside infrastructure

TEMPERATURE

Minnesota's average temperatures have risen each year from 1895 to 2016. The increase is most dramatic for the months of January (2.5 to 4.5 degrees of warming), February (five to seven degrees) and March (three to five degrees). Figure 1 shows the historical increases in the state's average annual temperature. The rate of increase is speeding up.[3] Analysis combining global climate models with historical climate data estimates that Minnesota temperatures may increase by 6 to 10°F in the winter and 7 to 16°F in the summer by 2100. This increase would result in a growing season that may be three to six weeks longer.[4] Increasing temperatures will also decrease the number of days of ice cover on Lake Superior. This will make shorelines more vulnerable to erosion and flooding and also extend the season for commercial navigation. Rising temperatures are driving species habitat migration and insect pests are surviving through milder winters.[5]

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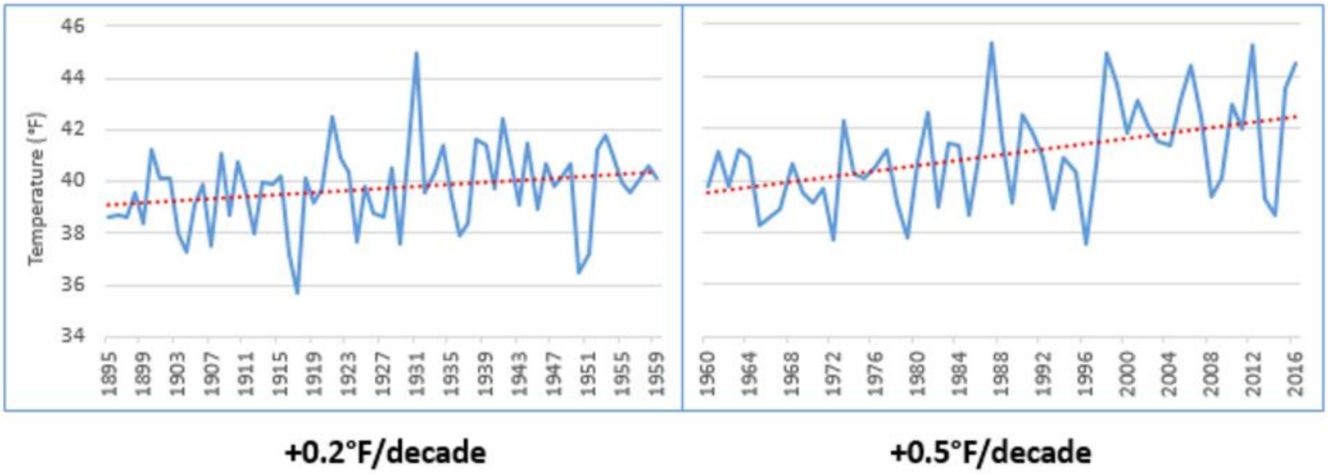
[3] Paul Moss et al., "Adapting to Climate Change in Minnesota: 2013 Report of the Interagency Climate Adaptation Team ," ed. Theresa Gaffey (Minnesota Pollution Control Agency, November 2013).
[4] Lucinda B. Johnson et al., "Impacts of Climate Change on Northern Ecosystems," (data derived from Wuebbles & Hayhoe, 2004).
[5] "Minnesota Climate and Health Profile Report: An Assessment of Climate Change Impacts on the Health & Well-Being of Minnesotans," MDH, 2015, http://www.health.state.mn.us/divs/climatechange/docs/mnprofile2015.pdf.

Figure 1: Minnesota's Average Annual Temperature, 1895-2016[6]

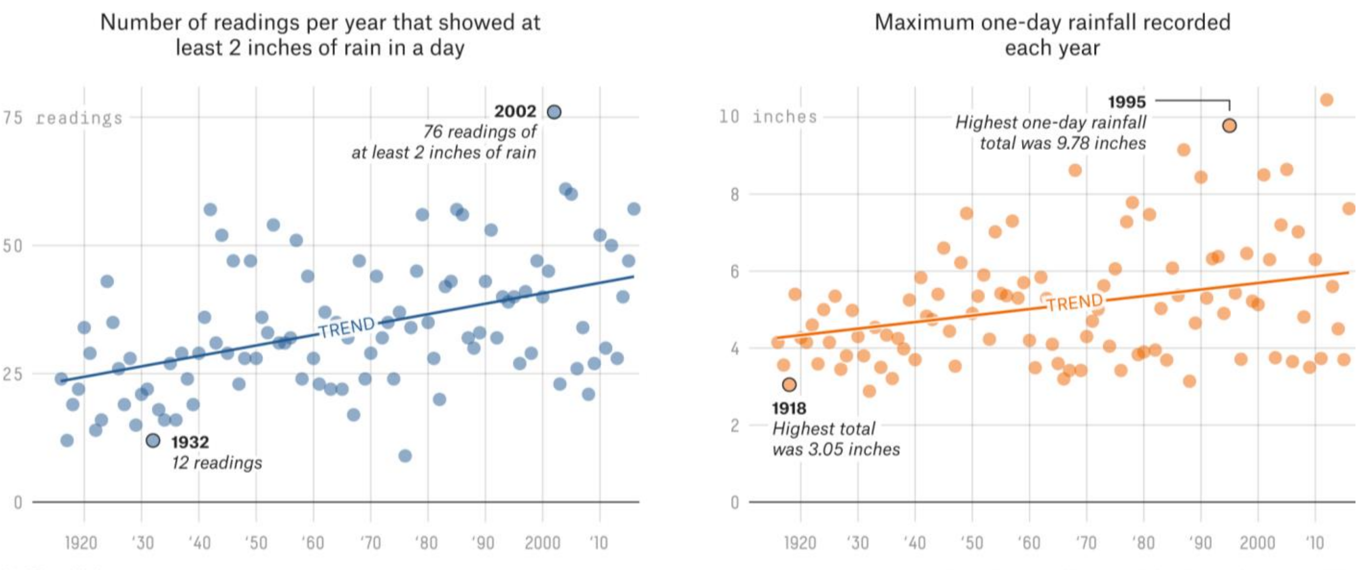


PRECIPITATION

Minnesota has always had large storms, but the frequency and intensity is changing. Historically, two-inch rain events occurred every five years for any given place throughout the state. Recently, the frequency of and intensity of heavy precipitation has increased. Since 1860, Minnesota has had 12 "mega-rain" events where at least six inches of rain falls on an area larger than 1,000 square miles—five have occurred since 2000. Over the last century the frequency of heavy rain events in Minnesota has increased while smaller rain events are less frequent (see Figure 2). The frequency of heavy rain events is expected to double by 2100.[7] These more extreme rain events often cause localized flooding which in turn can damage infrastructure and crops.

[6] "Climate 101: Climate & Health in Minnesota," Minnesota Department of Health, accessed June 22, 2021, https://www.health.state.mn.us/communities/environment/climate/climate101.html.
[7] Lucinda B. Johnson et al., "Impacts of Climate Change on Northern Ecosystems," (data derived from Wuebbles & Hayhoe, 2004).

Figure 2: Minnesota rain events, 1916-2016[8]



While annual precipitation between 2000 and 2016 has varied greatly, the average land area of the state classified as abnormally dry or drought-affected has also increased. Warming temperatures, changing weather patterns and an imbalance in water supply and demand can cause droughts.[9] The available data is from too short a time period to derive statewide drought trends, which is made even more challenging because there are few measurements of drought-related variables. Historically, droughts have been more common in southwest Minnesota compared to the northeast.[10] Droughts can impact water supply levels, soil health, shorten the growing season and create fire-prone conditions.

FLOODING

Flooding is the most expensive natural disaster in the world ($40 billion in average annual losses).[11] Nationwide, the average 100-year flood (a 1% chance of flooding annually) is expected to grow 45% and annual damages increase by $750 million by 2100. The types of flooding that will become more frequent include "localized floods," where rainfall overwhelms the capacity of drainage systems, and "riverine floods," where rainfall causes river flows to exceed the capacity of the river channel.[12] Increased flooding frequency is a major concern, because of the acute damage flooding events can cause to infrastructure.

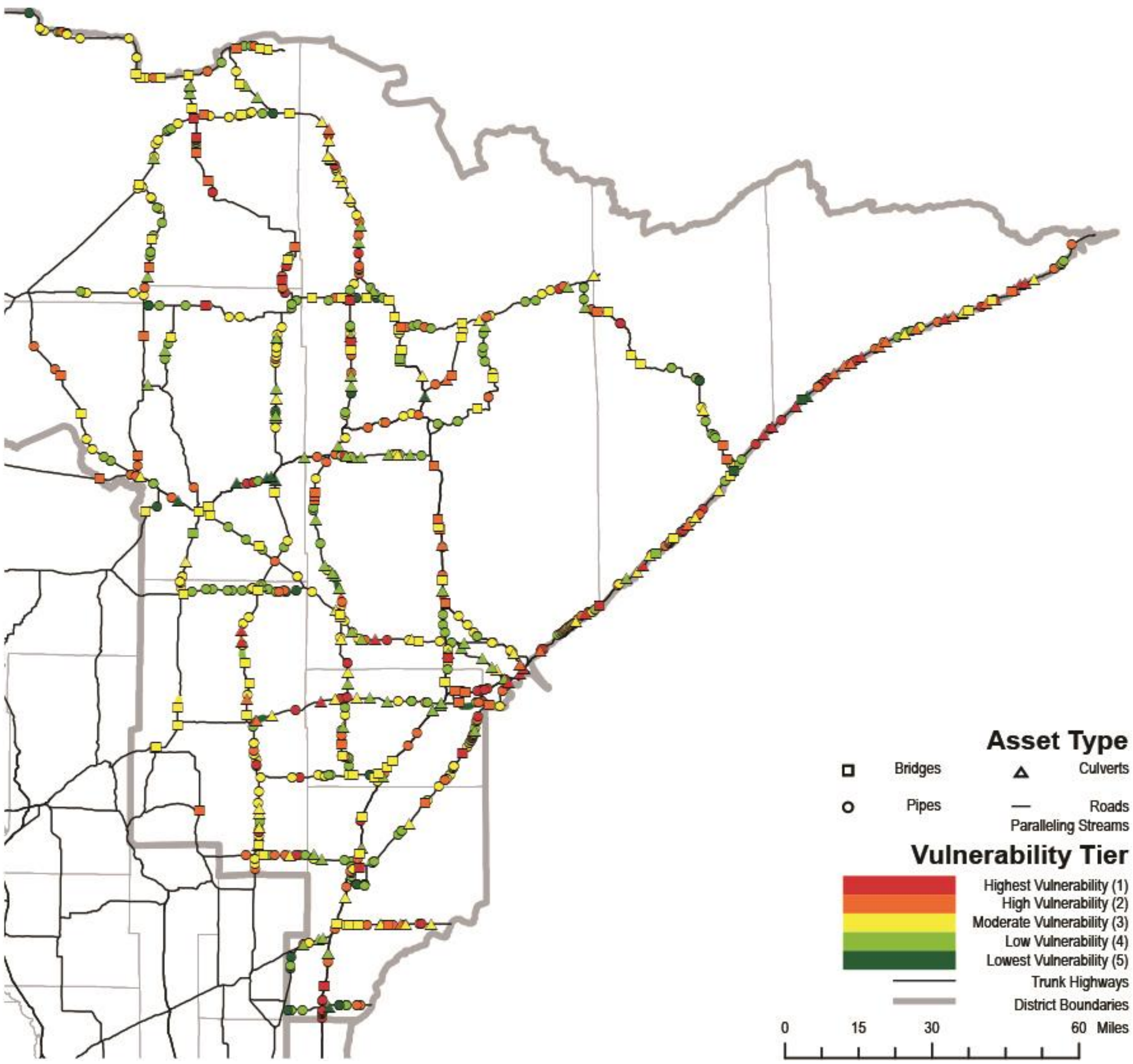
FLASH FLOOD VULNERABILITY AND ADAPTATION ASSESSMENT PILOT PROJECT

As part of one of 19 pilot studies across the country sponsored by Federal Highway Administration to examine the effects of climate hazards on transportation systems, MnDOT conducted a system-wide assessment of the trunk

[8] "Minnesota is Getting More and Bigger Rainstorms," Minnesota Department of Natural Resources, 2018, https://fivethirtyeight.com/wp-content/uploads/2018/05/koeze-flood-1.png.
[9] Melissa Denchak, "Drought: Everything You Need to Know," NRDC, September 13, 2018, https://www.nrdc.org/stories/drought-everything-you-need-know.
[10] "Minnesota State Hazard Mitigation Plan 2014," (Minnesota Department of Public Safety, 2014).
[11] Jeffrey J. Opperman, "A Flood of Benefits – Using Green Infrastructure to Reduce Flood Risk," The Nature Conservancy, 2014, https://www.conservationgateway.org/ConservationPractices/Freshwater/HabitatProtectionandRestoration/Pages/floodofbenefits.aspx.
[12] "Green Infrastructure," (Environmental Protection Agency, June 1, 2021), https://www.epa.gov/green-infrastructure.

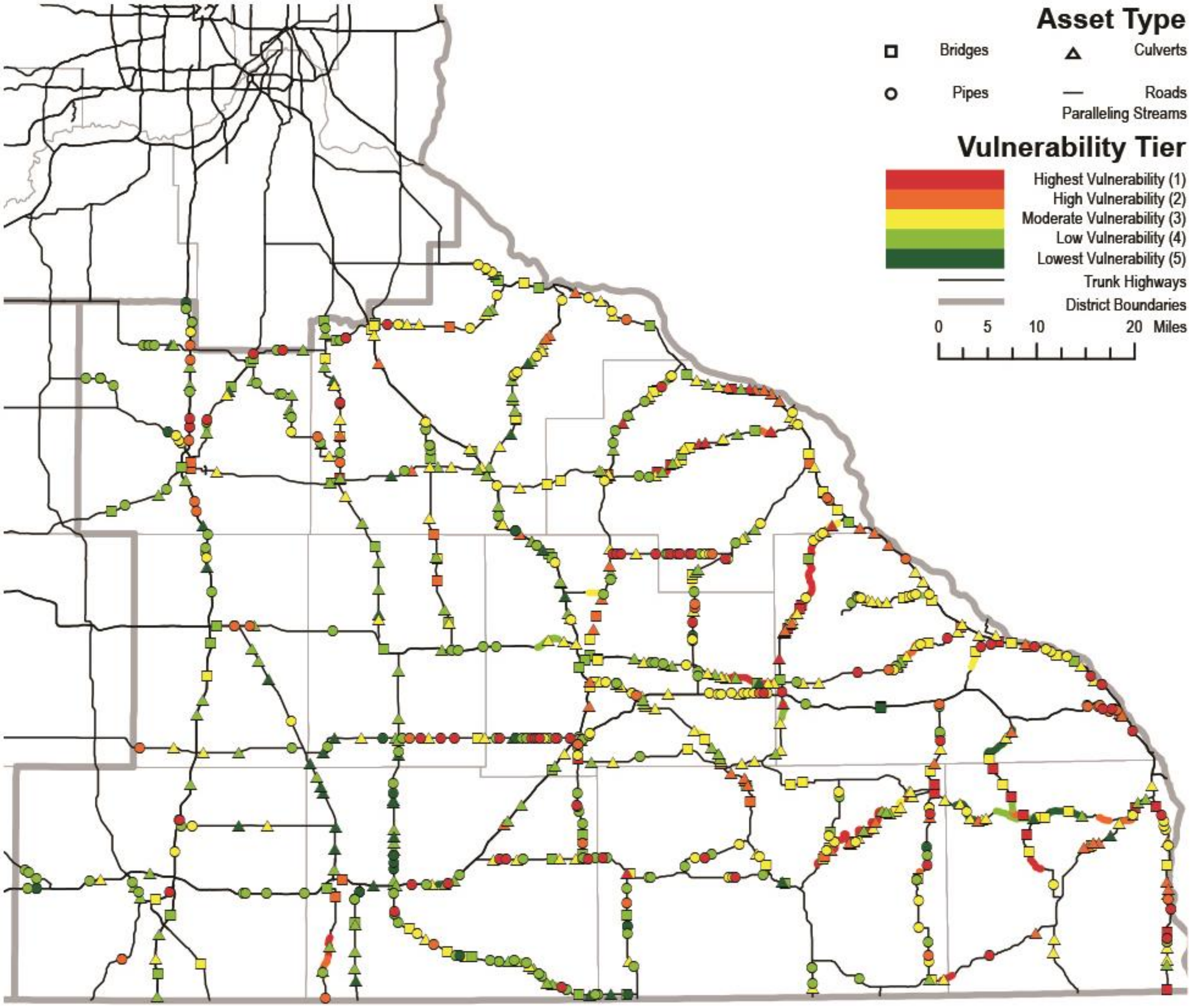
highway network's vulnerability to increased heavy precipitation in Districts 1 and 6 in northeast and southeast Minnesota respectively.[13] The project team scored and ranked 316 bridges, 521 large culverts, 920 pipes and approximately 45 miles of road segments paralleling streams based on their sensitivity and exposure to heavy precipitation as well as the system's adaptive capacity. The project also included an adaptation analysis of two culverts: one on MN 61 over Silver Creek in District 1 and a culvert on US 63 in the city of Spring Valley in District 6. The analysis evaluated the current performance of each culvert as well as three adaptation options. All options were assessed against three future climate scenarios and a preferred option was identified based on lowest lifecycle cost analysis, including direct repair and replacement costs as well as detour and safety costs. See Figures 3 and 4 for more detail on roadway vulnerability to flash flooding events in District 1 and District 6

Figure 3: Asset vulnerability to flash flood events in MnDOT District 1



[13] "Flash Flood Vulnerability and Adaptation Assessment Pilot Project," Minnesota Department of Transportation, accessed June 3, 2021, http://www.dot.state.mn.us/sustainability/pilotproject.html.

Figure 4: Asset vulnerability to flash flood events in MnDOT District 6



MnDOT is also currently developing a methodology to characterize the vulnerability of state bridges, large culverts and pipes to flooding.[14] This effort builds on the pilot project by expanding the scope of vulnerability assessment so that MnDOT can prioritize improvements using better inventory data. The tool will allow MnDOT to batch process (e.g. by district) vulnerability of bridges, culverts, and pipes using GIS and LIDAR datasets paired with selected future precipitation volumes (e.g. 10 year event, 25 year event, etc.).

[14] "Extreme Flood Vulnerability Analysis," Minnesota Department of Transportation, February 5, 2019, https://researchprojects.dot.state.mn.us/projectpages/pages/projectDetails.jsf?id=21038&type=CONTRACT&jftfdi=&jffi=projectDetails%3Fid%3D21038%26type%3DCONTRACT.

DATA ANALYSIS AND MODELING

Among extreme weather events, precipitation and storm events are particularly difficult to model at the regional or local scale. Geographically, extreme weather events such as flooding and heat waves are likely to become more acute in the southern half of the state.

The global scale of climate change models limits their ability to predict climate trends at smaller geographic scales. Even statewide predictions for Minnesota carry a high level of uncertainty regarding climate hazard risk, and the models are generally less reliable for predicting the intensity or frequency of extreme weather events.[15] Data limitations of both transportation asset inventories and regional climate conditions pose a significant barrier to advancing risk-based adaptation planning and evaluation.[16]

However, more up-to-date information on Minnesota's current climate is helping to reduce the transportation system's vulnerability to climate risks. In particular, Atlas 14 is a recent data source on precipitation frequency generated from rainfall-runoff models from the National Oceanic and Atmospheric Administration (NOAA). It allows for more precise flooding projections.[17] NOAA Atlas 14 estimates are used for hydraulic design on all state highway projects begun after June 30, 2014, which better accounts for precipitation frequency.[18]

Minnesota is working to develop more refined climate projection tools. The Climate Trends Tool by the Minnesota Department of Natural Resources is an interactive resource for graphing climate trends in Minnesota.[19] The Climate Explorer Tool recently released by the DNR incorporates the last climate models from the University of Minnesota to plot the projected climate trends in Minnesota.[20] Finally, the Minnesota State Legislature in 2021 approved funding the developing of dynamically downscaled climate information and the University of Minnesota has begun work on that effort.

In addition, MnDOT has selected a set of climate projections through the extreme flood vulnerability assessment and has developed estimates for 8 return periods (e.g. 10 year flood, 25 year flood, etc.) under select future scenarios.

CLIMATE MITIGATION AND ADAPTATION

Within transportation and infrastructure planning, there are broadly two types of climate activities – mitigation and adaptation. Mitigation focuses on reducing greenhouse gas emissions to manage the magnitude of future climate change. Adaptation focuses on bolstering the resilience and reducing the vulnerability of the transportation system to hazards generated by a changing climate.

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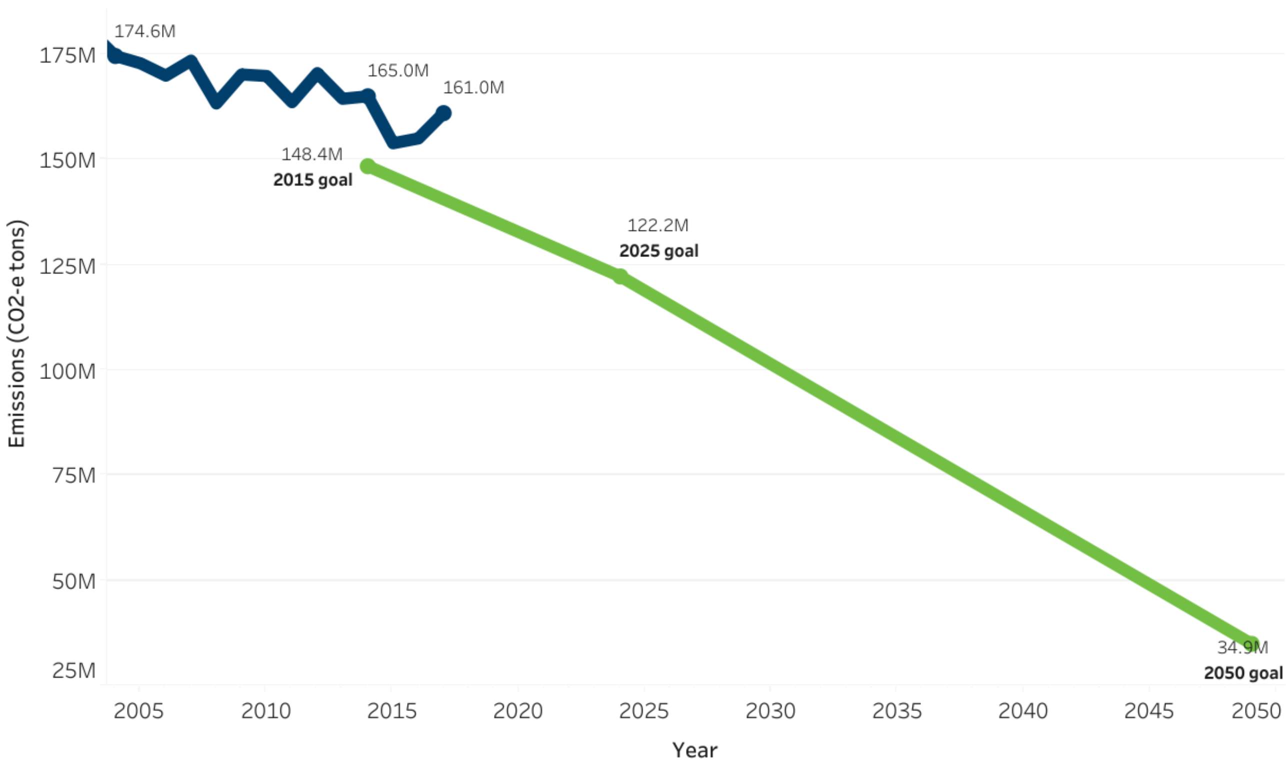
[15] Interview with Andrea Hendrickson, State Hydraulic Engineer, July 22, 2015.
[16] "Risk-Based Adaptation Frameworks for Climate Change Planning in the Transportation Sector – A Synthesis of Practice," (Transportation Research Board of the National Academies, 2013).
[17] NOAA, NOAA Atlas 14 Volume 8 Version 2.0, 2013, accessed April 30, 2021, http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume8.pdf.
[18] Ibid.
[19] "Climate trends," Minnesota DNR, accessed January 24, 2022, https://www.dnr.state.mn.us/climate/climate_change_info/climate-trends.html.
[20] Minnesota Climate Explorer, Minnesota DNR, accessed January 2022, https://arcgis.dnr.state.mn.us/ewr/climateexplorer/main/historical.

MITIGATION

In 2007, the Minnesota Legislature passed the Next Generation Energy Act that set a goal of reducing Minnesota's greenhouse gas (GHG) emissions 80% below 2005 levels by 2050. It also included interim targets of a 15% reduction by 2015 and a 30% reduction by 2030 (see Figure 5). The following year, the legislature established a specific goal of reducing GHG emissions from the state's transportation sector.[21] In October 2015, Governor Dayton signed a memorandum of understanding committing the state to work toward limiting the global average temperature from increasing more than 2°C.[22]

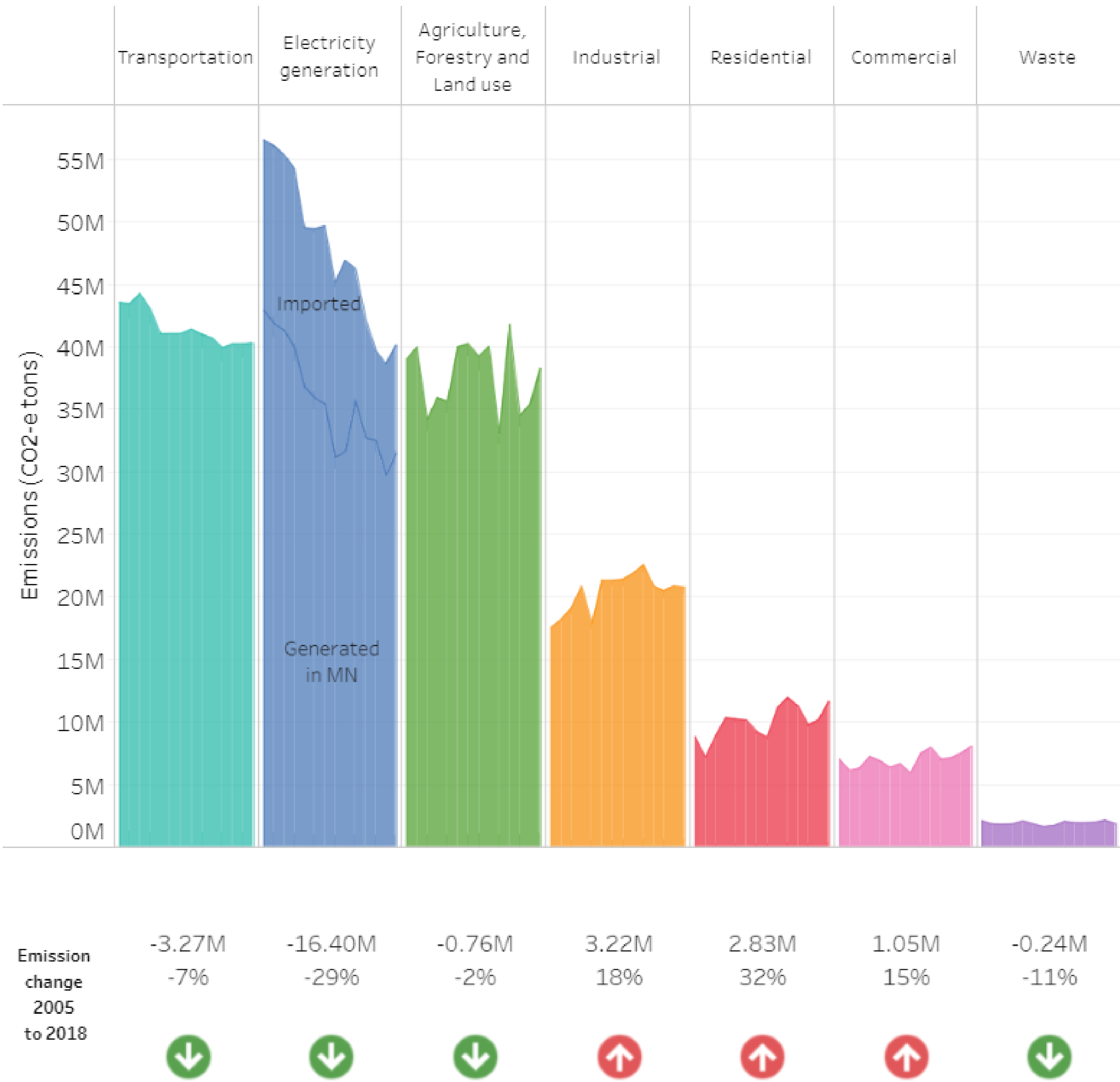
Figure 5: Minnesota's GHG emissions 1990-2018 (all sources) and Next Generation Energy Act goals[23]



[21] "Chapter 287--H.F.No. 3486," Minnesota Session Laws - 2008, Regular Session (Office of the Revisor of Statutes), accessed June 22, 2021, https://www.revisor.mn.gov/laws/2008/0/287/.
[22] "Global Climate Leadership Memorandum of Understanding," (State of Minnesota, 2015).
[23] "Greenhouse Gas Emissions Data," Climate Change in Minnesota (Minnesota Pollution Control Agency, November 10, 2020), https://www.pca.state.mn.us/air/greenhouse-gas-emissions-data.

While GHG emissions from the transportation sector have been declining since 2005, Minnesota did not meet the statewide 2015 emissions goal. Although continued declines are projected, emissions are still projected to be 10 to 15% higher than the 2030 reduction goal. As shown in Figure 6, the transportation sector is the largest emitter of GHG emissions as of 2016. However, other sectors like industrial, residential and commercial have grown, contributing to overall increases in GHG emissions.

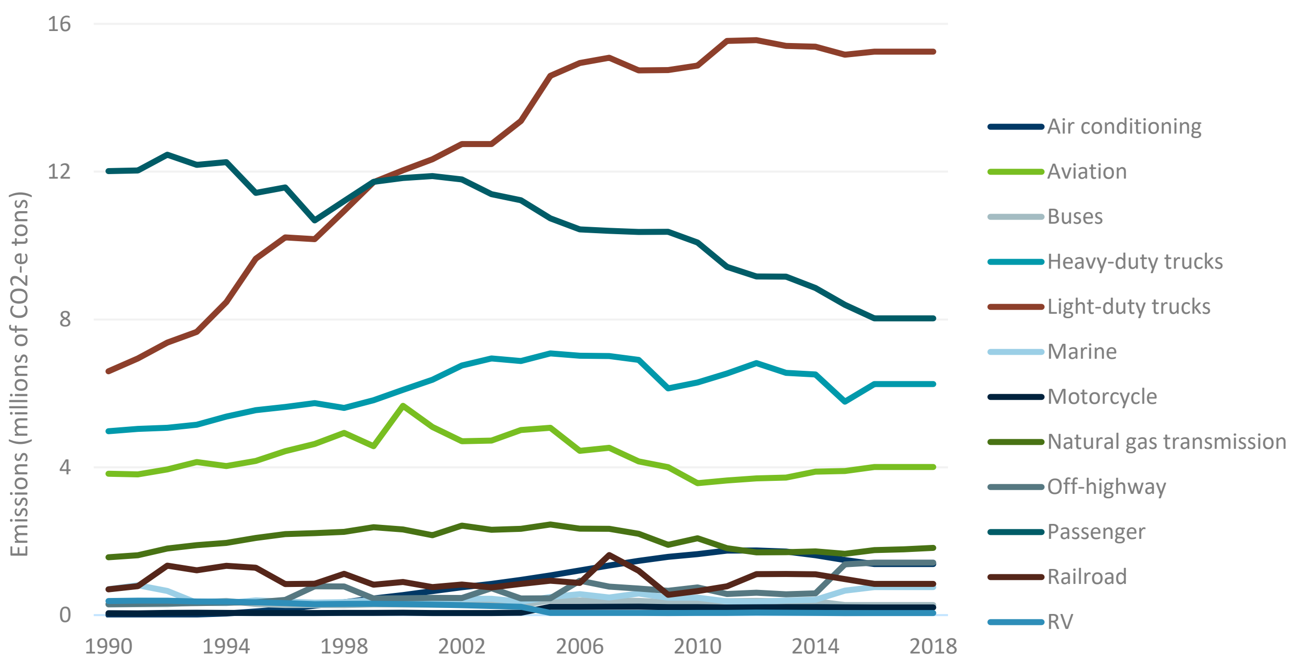
Figure 6: Emissions by source 2005-2018[24]



[24] Ibid.

Figure 7 shows historical transportation emissions from all transportation sources. Light-duty trucks and passenger cars generate the most emissions within the transportation sector. However, passenger vehicles have declined in emissions over time. Emission reductions in transportation are largely the result of slowing growth and reduction in vehicle miles traveled from 2005 through 2012 and increased vehicle efficiency driven by the federal fuel efficiency standards.

Figure 7: Historical transportation sector GHG emissions in Minnesota[25]



MnDOT reports annually on targets that were first established in 2016 and are used to track progress towards achieving sustainability goals statewide. Figure 8 shows climate targets that have been met (green circle) and not yet met (red square).

Figure 8: Transportation sector metrics from MnDOT 2020 Sustainability Report[26]

CATEGORY	TARGET	RESULTS (2019-2020)
Transportation sector GHG emissions	30% reduction from 2005 levels by 2025	7% reduction (green circle)
Vehicle miles traveled	MnDOT is working with partners to adopt a VMT reduction goal	1% increase (2018-19) (red square)
Electric vehicles	20% of statewide light-duty vehicles are electric by 2030	18,749 EVs registered (0.4% total) (red square)

[25] Ibid.

[26] "2020 MnDOT Sustainability and Public Health Report," (MnDOT, 2021).

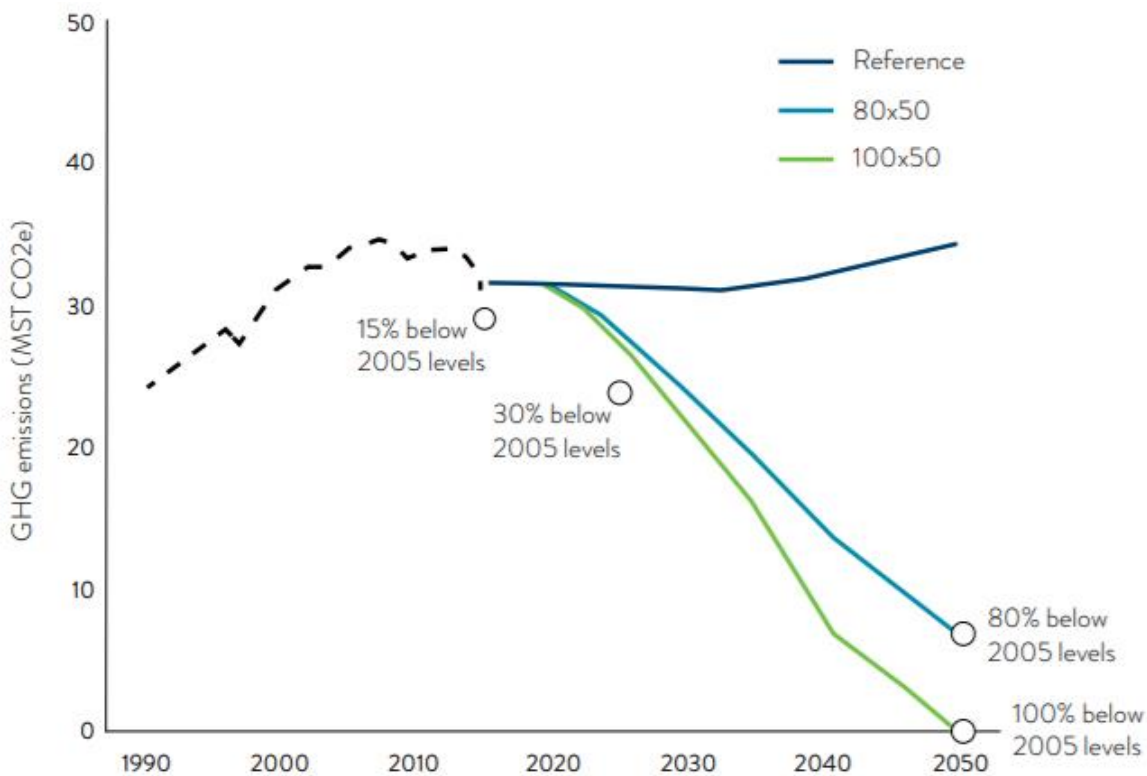
PATHWAYS TO DECARBONIZING

In 2019, MnDOT, in partnership with multiple state agencies, studied opportunities to reduce GHG emissions from surface transportation.[27] The project team modeled three future scenarios of emissions based on different assumptions:

1. Reference scenario: "business as usual," including current policies and assumed federal fuel economy standards would be weakened by 2021.
2. 80 x 50 Scenario: Combination of strategies to achieve 80% statutory Next Generation Energy Act GHG reduction goal for 2050.
3. 100 x 50 Scenario: Combination of strategies to achieve zero emissions from transportation by 2050. To achieve economy-wide GHG reduction goals, transportation would need to compensate for other sectors where targets are harder to achieve.

Figure 9 shows the scenarios in reduction of greenhouse gas emissions over time. Each scenario had different assumptions within similar categories (e.g. type of transportation or fuel). Assumptions included actions like extending federal fuel economy standards, increased electric and hybrid vehicle sales, increased electric and compressed natural gas buses and decline in biodiesel carbon intensity.

Figure 9: Total surface transportation emissions by scenario[28]



[27] "Pathways to Decarbonizing Transportation in Minnesota," (MnDOT, 2019).
[28] Ibid.

The largest impacts to the model were changes in vehicles and fuels, not in reducing vehicle miles traveled. Recommendations from the study include:

- Adopt clean car standards
- Strengthen petroleum replacement goals
- Expand biofuel infrastructure
- Expand the use of higher biodiesel blends and renewable diesel
- Facilitate ways to use renewable diesel in Minnesota
- Create incentives for measures that reduce the carbon impact of biofuels

This study has paved the way for future work by MnDOT to decarbonize transportation.

CLIMATE ADAPTATION

Adaptation involves actions to reduce vulnerability and increase resilience of the transportation system in anticipation of climate change and associated extreme weather events.[29] Adaptation can be incorporated into transportation through asset management, long range transportation planning, design and construction, operations and maintenance and emergency management. Adaptation considerations reduce the impacts of climate-related stresses (longer-term trends that increase vulnerability) and shocks (extreme weather events).

Currently, state departments of transportation, metropolitan planning organizations (MPOs), local planning agencies and federal land management agencies may use federal-aid highway funds for vulnerability and risk assessments related to climate change and extreme weather on federal-aid highways.[30] Adaptation activities are usually informed by vulnerability assessments.[31]

INFRASTRUCTURE PLANNING AND DESIGN

Transportation can adapt to climate change with careful planning and design for asset management, capital planning, operations and maintenance functions. These impacts and strategies are summarized in Increased flooding frequency is a major concern, because of the acute damage flooding events can cause to infrastructure.

FLASH FLOOD VULNERABILITY AND ADAPTATION ASSESSMENT PILOT PROJECT

As part of one of 19 pilot studies across the country sponsored by Federal Highway Administration to examine the effects of climate hazards on transportation systems, MnDOT conducted a system-wide assessment of the trunk highway network's vulnerability to increased heavy precipitation in Districts 1 and 6 in northeast and southeast Minnesota respectively. The project team scored and ranked 316 bridges, 521 large culverts, 920 pipes and approximately 45 miles of road segments paralleling streams based on their sensitivity and exposure to heavy precipitation as well as the system's adaptive capacity. The project also included an adaptation analysis of two culverts: one on MN 61 over Silver Creek in District 1 and a culvert on US 63 in the city of Spring Valley in District

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[29] TRB, Climate Change, Extreme Weather Events, and the Highway System, 2014.
30 John R. Baxter, Joyce A. Curtis and Gloria M. Shepherd. Letter to Directors of Field Services, Directors of Technical Services, Division Administrators and Federal Lands Highway Division Engineers. *INFORMATION: Eligibility of Activities To Adapt To Climate Change and Extreme Weather Events Under the Federal-Aid and Federal Lands Highway Program*, September 24, 2012.
[31] "Assessment of the Body of Knowledge on Incorporating Climate Change Adaptation Measures into Transportation Projects," (ICF International, USDOT, 2013).

6. The analysis evaluated the current performance of each culvert as well as three adaptation options. All options were assessed against three future climate scenarios and a preferred option was identified based on lowest lifecycle cost analysis, including direct repair and replacement costs as well as detour and safety costs. See Figures 3 and 4 for more detail on roadway vulnerability to flash flooding events in District 1 and District 6

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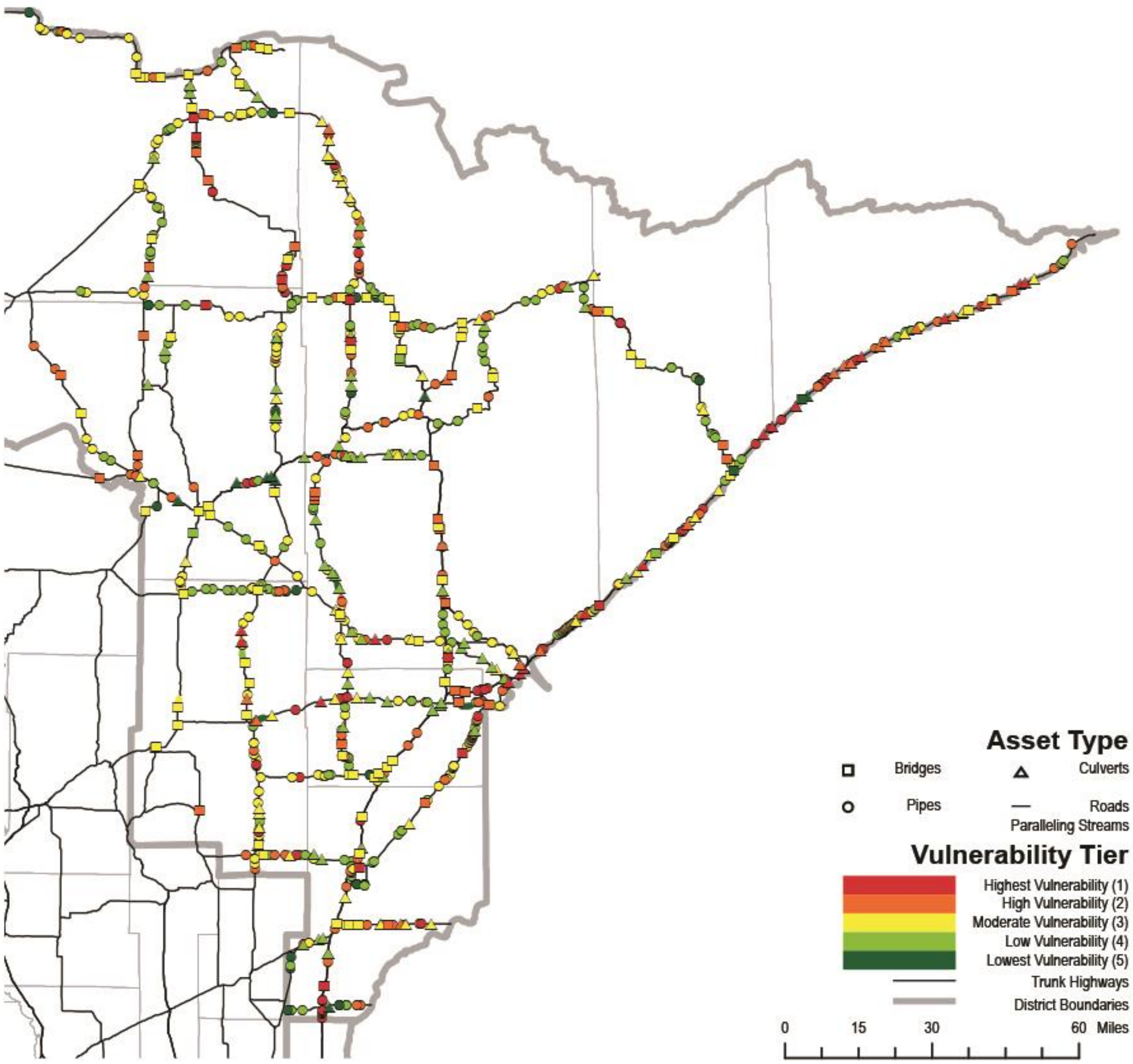
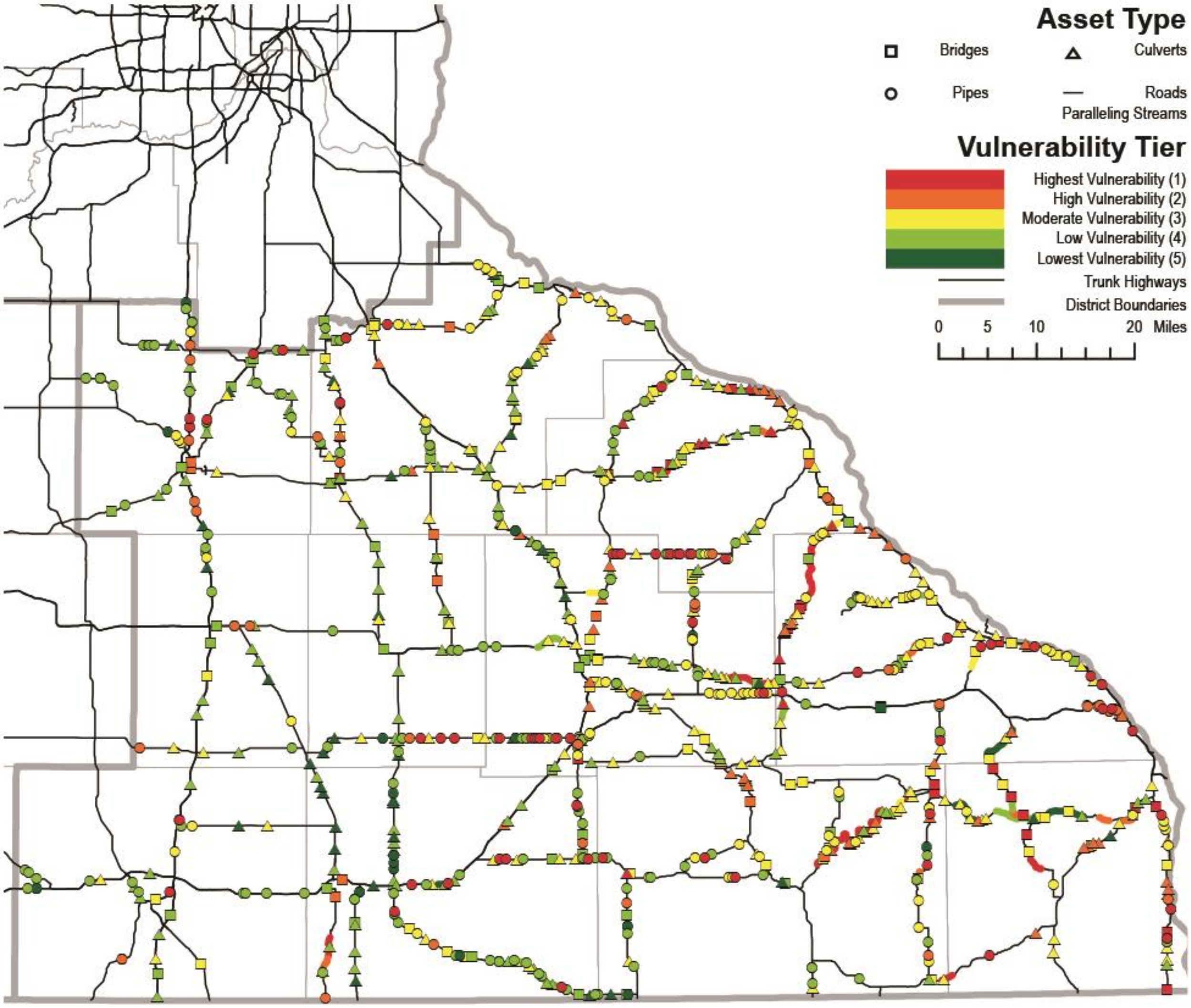


Figure 4: Asset vulnerability to flash flood events in MnDOT District 6



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2 below.

Table 2: Potential climate change adaptation strategies

Phase	Potential Climate Change Adaption Strategies
Planning & Project Selection	• Establish planned evacuation routes • Relocate infrastructure and communities at risk • Integrate climate risk hazards into asset management plans • Plan for accelerated pavement and asset degradation due to increased weathering
Project Design	• Incorporate adaptation assessments into project scoping and design selection • Adjust design life of infrastructure relative to climate hazard risks • Expand best management practices to improve drainage and stormwater storage at project sites
Project Construction	• Prepare crews for work hazards related to extreme weather • Plan for increased weather delays and potentially more *force majeure* claims
Maintenance & Operations	• Increase maintenance frequency for pavements and electrical systems • Address safety concerns for maintenance workers during extreme weather events • Plan for road closures and traffic incidents during extreme weather events • Plan for increased ice removal operations • Increase culvert and bridge inspections • Increase frequency of debris removal

DESIGN IMPLICATIONS

Transportation infrastructure consists of subsurface conditions, materials specifications, cross sections and standard dimensions, drainage and erosion and structure and location engineering.[32] Approaches to changing design standards to address climate change are similar to those made to building codes to adapt to earthquakes. Research on materials, soils and structures has informed how design can increase buildings' resilience to forces applied by seismic events.

A barrier to considering climate change impacts in infrastructure design is the misaligned terminologies of extreme weather events used by climate scientists and design events used by engineers. For example, engineers refer to bridges in terms of 100-year design lives and design events, whereas climate scientists refer to a ten-year

[32] Nicholas Schmidt and Michael D. Meyer, "Incorporating Climate Change Considerations into Transportation Planning," *Transportation Research Record: Journal of the Transportation Research Board* 2119, no. 1 (January 1, 2009), https://doi.org/10.3141/2119-09.

storm as an extreme weather event. Climate models additionally predict rainfall on a daily basis (sometimes reporting only monthly or annual average rainfall), which is not an appropriate timeframe for most hydraulic design.[33]

One strategy to account for greater uncertainty in the long-term is to design infrastructure with shorter useful lives, which creates more opportunities to change the design to reflect new and more up-to-date climate data and design standards. This does not align with MnDOT's current asset management strategy to keep the state's assets in service for as long as possible.[34] There is need for engineering design standards to reflect increased water stress and other environmental factors in the short term and increased temperatures, temperature ranges and wind load in the long term.

This can be particularly challenging given the combination of needing to design for more water but not pass it downstream. Passing additional water downstream risks increased stress on other infrastructure (MnDOT's or other jurisdictions'), potentially increasing the overall impact to Minnesotans.

TRANSPORTATION AGENCY INITIATIVES

MnDOT has several initiatives to address climate change through mitigation and adaption. Other states across the nation are also working to address localized effects of climate change and plan for the future.

MNDOT

MnDOT established the Office of Sustainability and Public Health in 2017. Since then, the office has undertaken a variety of initiatives that build on their four focus areas:

1. Reduce carbon pollution from the transportation sector.
2. Increase operational efficiencies that support Executive Orders, including efforts to reduce fuel consumption and energy use.
3. Improve resilience of the transportation system to climate change and other natural and human disruptions.
4. Promote public health in transportation decision making.

MnDOT's climate related initiatives include:

- *Pathways to Decarbonizing Transportation:* The purpose of this project was to explore opportunities for GHG emission reductions from surface transportation: passenger cars and trucks, medium-duty and heavy-duty trucks, buses, motorcycles, and mobile air conditioning. It was a collaboration between the Minnesota Department of Transportation, Department of Commerce, Department of Agriculture, Minnesota Pollution Control Agency, the Environmental Quality Board and the McKnight Foundation.
- *Sustainable Transportation Advisory Council (STAC):* The goal of the STAC is to help Minnesota transition to a low-carbon transportation system in a way that is consistent with statutory goals for energy and

[33] Interview with Andrea Hendrickson, MnDOT Hydraulics Engineer.
[34] "Transportation Asset Management Plan (Draft), Chapter 6: Life Cycle Cost Considerations," (MnDOT, 2014).

emissions reductions and maximizes benefits to Minnesota, while recognizing the importance of continued work towards improving safety, reducing inequities and supporting economic development.

- *Sustainability Reporting:* The annual MnDOT Sustainability Report outlines the agency's sustainability goals, progress and strategies for achieving the goals.
- *Climate Resilience:* The agency is currently developing a process for evaluating future flood risk to MnDOT bridges, large culverts and pipes.
- *Greenhouse Gas Emissions Analysis:* In 2020, MnDOT began quantifying GHG emissions as part of the environmental review process.
- *Solar Energy:* Executive Order 19-27 directs state agencies to reduce GHG emissions 30% from 2005 levels by 2025 and facility energy use 30% from 2017 levels by 2027. MnDOT is exploring how solar energy development on our right-of-way can help meet MnDOT energy needs, reduce long-term operational costs and reduce GHG emissions.
- *Electric Vehicles (EVs):* MnDOT is evaluating the revenue implications of higher efficiency for all vehicles, with a focus on EVs that use all or mostly electricity for fuel.
- *Salt Sustainability:* MnDOT is researching and piloting ways to meet the public and economic demands for safe winter driving conditions, while optimizing the use of salt.

OTHER STATES

Examples of how other transportation agencies are addressing climate change through their own work are summarized in the following sections.

VERMONT: RIVER SCIENCE TRAINING

The Vermont Agency of Transportation (VTrans) developed a River Science Climate Resilience Strategy in partnership with the Agency of Natural Resources. This work required river science training for certain engineering and operations staff. It also helped VTrans modify its hydraulics manual and roadway slope designs to account for river movements and soil erosion. VTrans went on to retrofit roads and bridges to increase their resilience to flooding. This also addressed pollutant runoff concerns for the state's lakes and streams. This effort won a 2015 Environmental Excellence Award from the Federal Highway Administration.[35]

NEW MEXICO: INTEGRATE LAND USE AND TRANSPORTATION PLANNING WITH CLIMATE CHANGE

The Central New Mexico Climate Change Scenario Planning Project (July 2013 - Spring 2015) used scenario planning to develop a strategy for the Albuquerque region to reduce future greenhouse gas emissions and prepare for climate change impacts. The scenarios informed development of the state's long-range transportation plan, and related planning efforts at the state, local and federal level.[36] The project demonstrated to stakeholders

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[35] "Climate Change Adaptation and Resilience: River Science Climate Resilience Strategy," 2015 Environmental Excellence Awards (U.S. Department of Transportation/Federal Highway Administration, 2015), https://www.fhwa.dot.gov/environment/environmental_excellence_awards/eea_2015/page02.cfm.

[36] "Central New Mexico Climate Change Scenario Planning Project," US Department of Transportation/Volpe National Transportation Systems Center, October 30, 2015, https://www.volpe.dot.gov/transportation-planning/public-lands/central-new-mexico-climate-change-scenario-planning-project.

that certain patterns of development are more resilient to climate impacts than others. This highlighted the important feedbacks between land development and transportation systems.

ALASKA: PERMAFROST PROTECTION AND EVACUATION ROUTES

The Alaska Department of Transportation and Public Facilities is pursuing adaptation efforts such as permafrost protection, drainage improvements, flood mitigation and development of evacuation routes and shelters. For evacuation routes, the FHWA provided funding to raise elevation of existing roads above flood levels and to extend an evacuation road.[37]

WASHINGTON STATE: "MAINSTREAMING" CLIMATE ADAPTATION INTO NEPA/SEPA REVIEW

Washington state's Department of Transportation (WSDOT) Environmental Stewardship Office developed guidance in 2009 for undertaking project-level climate change evaluations. They became the first DOT in the nation to incorporate climate change and greenhouse gas emissions into cumulative effects analysis mandated under national and state Environmental Policy Acts (NEPA and SEPA).[38] The guidance is based on climate information generated from the *Washington Climate Change Impacts Assessment* and a statewide vulnerability assessment of WSDOT's assets. The guidance provides a standard qualitative language template on cumulative effects. It requires project teams to document climate threats in the project area and document how the project will be designed to be resilient or resistant to climate threats.

INTERNATIONAL

The Federal Highway Administration conducted a review of transportation agencies in the United Kingdom, New Zealand, Australia, Denmark, Norway, the Netherlands, Canada and South Korea on how they are addressing climate adaptation through frameworks, strategies, measures, risk assessments, long-range planning and land use, changes in design standards, maintenance and operations, asset management and research.[39] These agencies face common challenges: uncertainties of the impacts and timeframes of future climate variability and GHG emissions, and adaptation needs that exceed current funding availability. They recognize that it is often more cost-effective to "climate proof" infrastructure during the construction phase, rather than to adapt infrastructure once it is in operation. This results in focus on adaptation planning during the scoping phase of new infrastructure projects. Adaptation considerations are most commonly integrated into planning and design of infrastructure that interfaces directly with hydrological systems, including drainage systems, bridges and culverts. While agencies recognize the potential impacts of climate change on maintenance and operations, few are making changes to these activities at this time. Adaptation is focused on infrastructure planning and design.

RELATED TRENDS

- Aging infrastructure
- Air Quality

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[37] "Climate Change in Alaska: Transportation Infrastructure and Climate Change," (Alaska Department of Transportation and Public Facilities, 2009). http://climatechange.alaska.gov/docs/afe09/9_Coffey.pdf.
[38] Washington State Department of Transportation, Guidance for NEPA and SEPA Project-Level Climate Change Evaluations, 2014, accessed April 30, 2021 http://www.wsdot.wa.gov/NR/rdonlyres/BDF7C3DA-4F27-4CD5-8D02-6813027A928B/0/WSDOT_ClimateGuidance.pdf.
[39] "International Practices on Climate Adaptation in Transportation: Findings from a Virtual Review," (US Department of Transportation/Federal Highway Administration, 2015).

- Biodiversity
- Electrification and Alternative Fuels
- Health and Transportation
- Urban and Rural Population Trends
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REVISION HISTORY

Date	Summary of revisions
January 2016	Original paper.
February 2022	Updated with new data and information.