

Transportation Resilience: Current Practices and Opportunities for MnDOT

Minnesota Department of Transportation

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Executive Summary

In Minnesota, climate change is already having major impacts, and our winters are warming faster than any other state in the continental USA¹. Given that these impacts are projected to increase, the Minnesota Department of Transportation is implementing climate adaptation measures along with mitigation actions. This report provides an overview of climate change impacts in Minnesota, describes current MnDOT efforts related to climate adaptation, and highlights gaps and opportunities based on DOT best practices and staff recommendations.

Climate change impacts include higher and more varied temperatures, precipitation levels, and frequency of extreme weather events. These amplify stress to the transportation system, impact the way Minnesotans travel, and increase the cost of building, operating and maintaining transportation infrastructure. The International Panel on Climate Change (IPCC) [report](#), released by the United Nations, and the [National Climate Assessment](#) shared similar scientific findings that climate change will present growing challenges to human health and safety, quality of life, and the rate of economic growth in the US and around the world. Further, in the Midwest, at-risk communities are becoming more vulnerable to climate change impacts, especially tribal nations because of their reliance on threatened natural resources. It is very important that planners and technical experts understand that climate science changes how the environmental context is described. No longer can organizations look only at the past climate and weather conditions – they must also examine the future climate forecast.

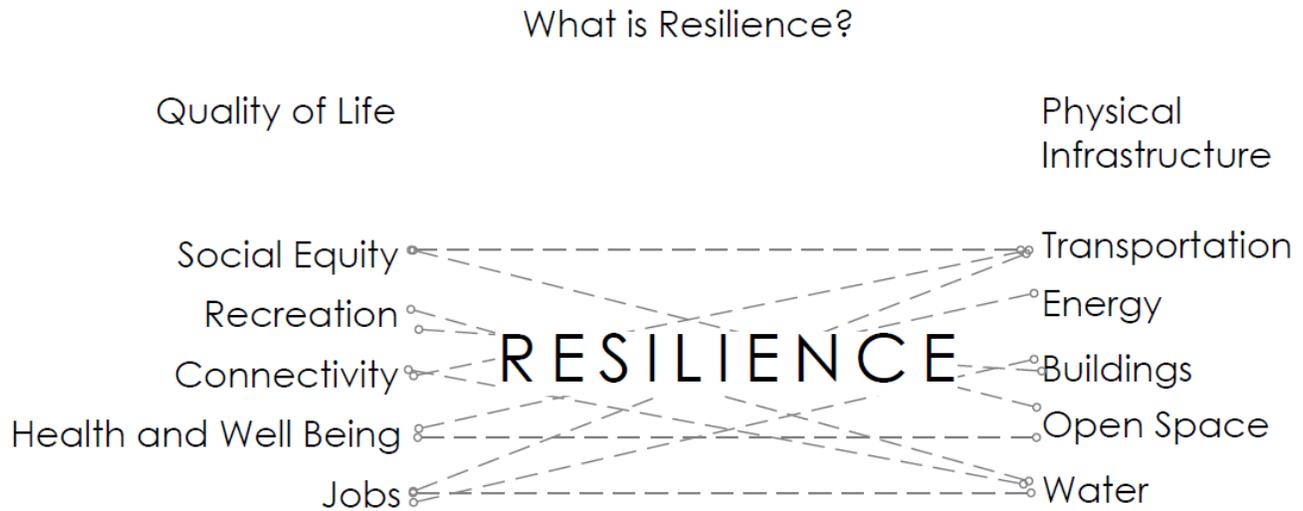
MnDOT is committed to providing a resilient transportation system that serves Minnesota as our climate changes. The agency's 20-Year Statewide Multimodal Transportation Plan identified transportation system resilience as a key concept (see definition in footnote²), and more generally resilience can be defined as the capacity of individuals, communities, institutions, businesses, and systems to survive, adapt, and grow, no matter what kinds of chronic stresses and acute shocks they experience. Example of shocks are fires, drought, and floods; and examples of stresses are early snow melt in the spring and more winter freeze/thaw cycles. For the purposes of this report, **the analysis of resilience focuses on the climate adaptation aspects**, and does not include broader aspects of the term such as disaster response and cyber security.

Figure 1 illustrates how resilience is built on the interconnectedness of quality of life and physical environment, with transportation being a critical element.

¹ A summary of fastest warming winters by states can be found on ClimateCentral.org and [here](#).

² MnDOT SMTP defines resilience as: "System resiliency refers to reducing vulnerability and ensuring redundancy and reliability to meet essential travel needs. The transportation system is vulnerable to many types of threats and risks, such as severe weather, acts of terrorism and cyber-attacks. Advanced preparation as well as mitigation and adaptation to threats and risks helps to ensure the people and goods are able to continue to travel during emergencies."

Figure 1: Example of Underlying Connections that Build Resilience³



Resilience

Resilience can be seen as the ability of the physical environment to respond to forces; we as the people can equip the physical environment to respond to forces in a positive way. Therefore, the questions we need to ask are: is the physical environment increasing the quality of life? Is the physical environment aiding natural systems? We can implement green infrastructure that not only aids in the combat of climate change but also increases the quality of life for neighborhoods, communities, and all of Providence.

MnDOT staff reviewed FHWA studies and several state DOT programs and conducted interviews with DOT staff in other states to learn about their climate adaptation efforts. Interviewees identified two key actions for MnDOT to consider: 1) analyze infrastructure vulnerability and 2) develop policies that incorporate changing weather patterns into infrastructure design.

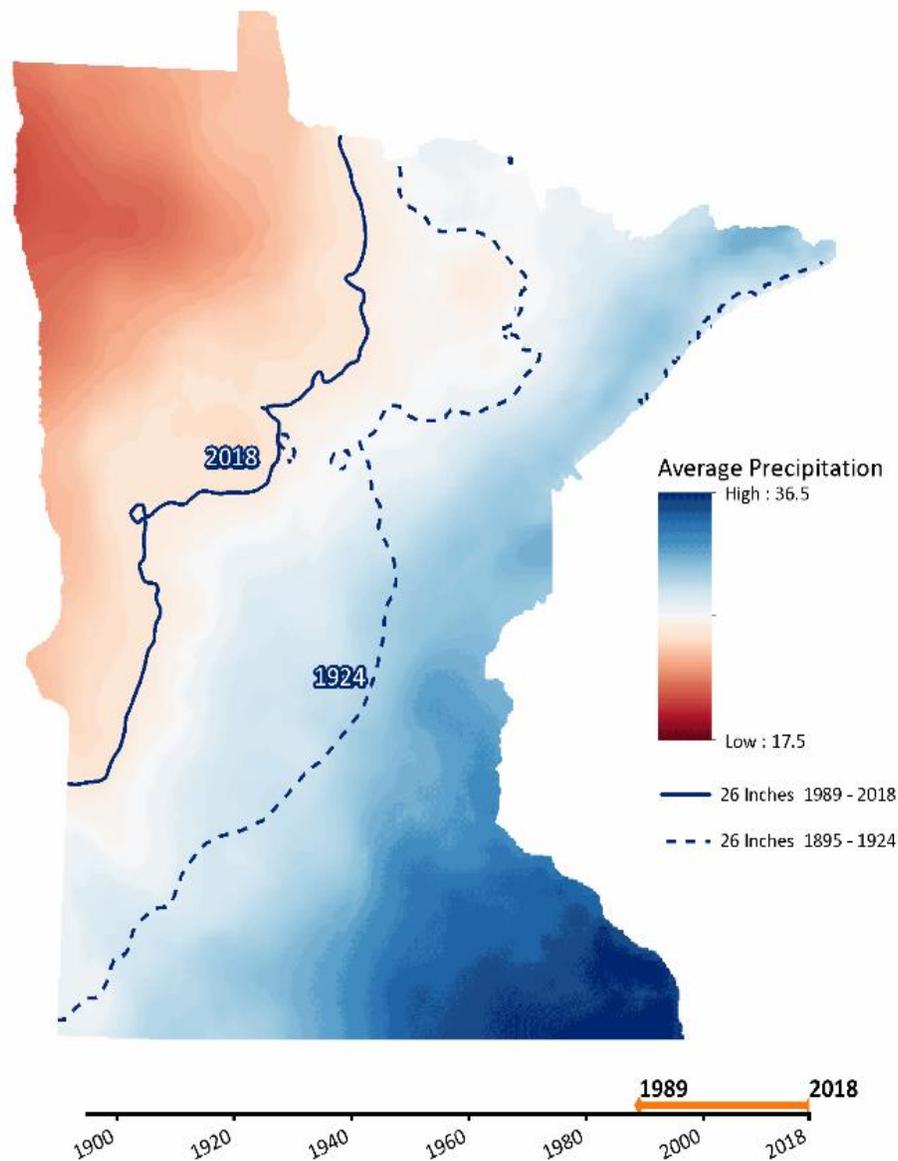
This document is only a snapshot in time, and things will change as MnDOT continues to advance climate resilience. MnDOT is on the leading edge in considering how the changing climate is impacting its assets and the people who depend on them. To further advance this work, MnDOT is assessing future flood risks, engaging in equity conversations, and studying how freeze/thaw cycles have been changing. The information gained from these efforts informs MnDOT's understanding of vulnerability, planning processes, and designing policy.

³ Source: City of Providence, RI

Climate Impacts

Minnesota is getting wetter and warmer due to climate change. Table 1 provides an overview of the negative impacts of climate change on the transportation system in Minnesota. Increased precipitation and larger, more frequent extreme storm events are the most likely changes and will have significant implications for infrastructure design, storm water, and erosion. Figure 2 shows how precipitation patterns have already shifted, with a larger portion of the state receiving more than 26 inches of rain in a typical year in the 2000s vs 1920s ([see the animated graphic here](#)). Minnesota is already warming – particularly in the winter – which will change freeze/thaw cycles and shift species habitat. In the coming decades, increases in high heat and heat waves are also expected, which impact public health, road surface buckling, and landscape maintenance. Figures 3 shows how quickly winter temperatures have been warming, with the 30-year daily winter lows shifting significantly.

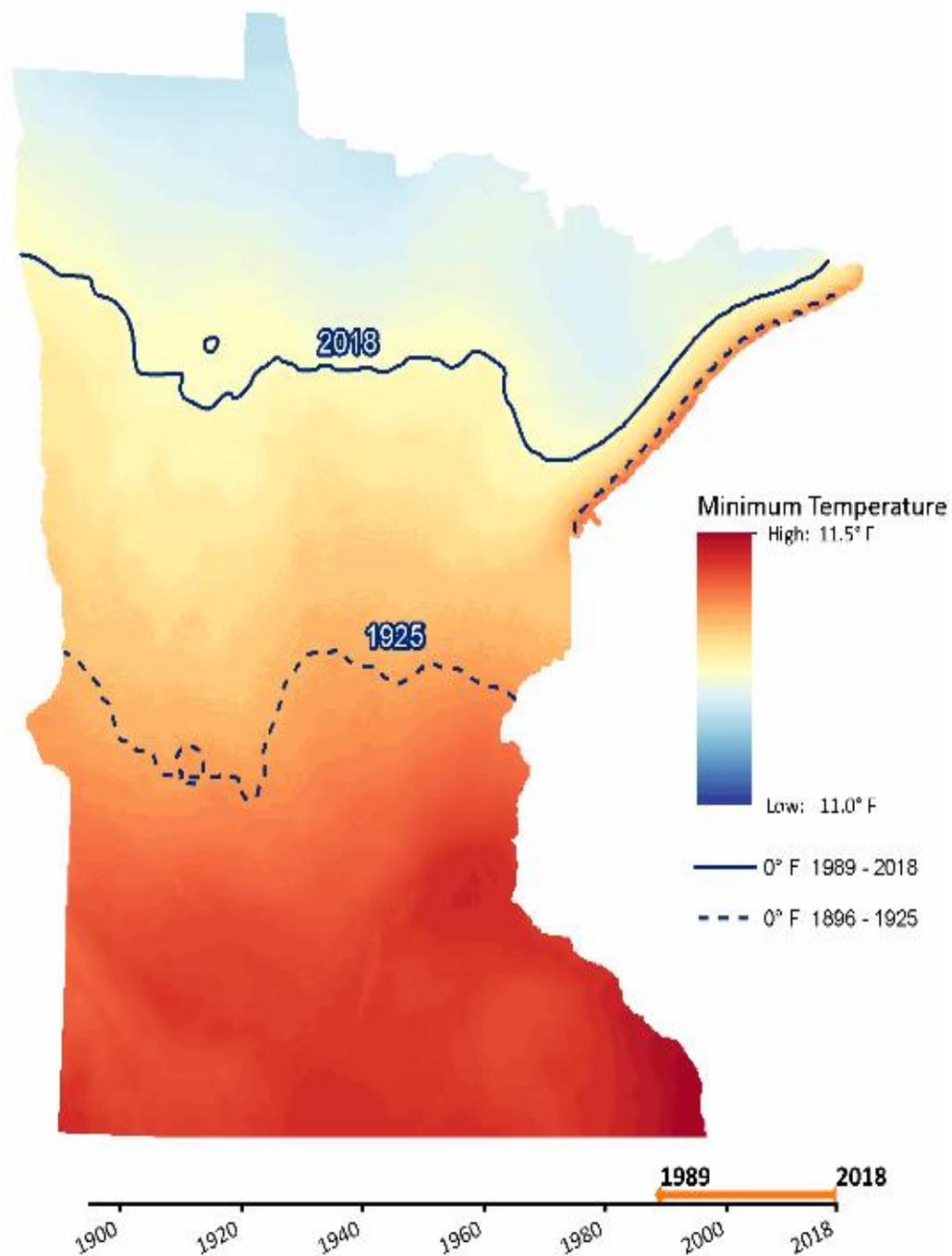
Figure 2: Shift in 30-year Average Annual Precipitation Since 1924



Source: [Minnesota Department of Natural Resources Historical Climate webpage](#)

Figure 3 below plots the average daily minimum temperature for each winter since 1896, and presents a clear increase ([see animated graphic here](#)).

Figure 3: Minnesota Average Winter Daily Minimum Temperatures



Source: [Minnesota Department of Natural Resources Historical Climate webpage](#)

Table 1: Potential Effects and Implications for Transportation of Climate Change in Minnesota

Climate Impacts	Likelihood this will change in MN over the next 20 years	Potential Negative Implications for the Transportation System
Heavy Precipitation / Flooding	Very High	<ul style="list-style-type: none"> • Damage to infrastructure (highways, rail, airport runways, etc.) • Increase in detours and slowed operations / performance from flooded roads • Slope failures and erosion • More mudslides, sink holes, road bed failure • Increased large-scale river flooding (bridge scour, roadway erosion, inundation) • More localized flooding due to poor drainage or higher groundwater table • More frequent and extensive inundation of low-lying areas (both temporary and permanent) • Disruption of construction projects, both delays and damage/deterioration to sites
Warmer Winters	Very High	<ul style="list-style-type: none"> • Increase in overnight icing • Likely increase in freeze/thaw cycles (and potentially increased salt use) • Reduced pavement conditions and life cycles length • Change in storm track with some extreme storms with higher than normal snow accumulation • Increase in average winter precipitation and more extreme precipitation • Change in timing of precipitation (more rain, less snow) • Increase in damage from ice storms and downed powerlines (less certainty)
New Species Ranges <i>(mainly due to warmer winters)</i>	High	<ul style="list-style-type: none"> • Changes in roadside vegetation mixes • Soil erosion from vegetation loss • Increase in invasive species populations • Increased exposure of construction and maintenance crews to vector borne diseases • Wetland site failure
Drought	Medium	<ul style="list-style-type: none"> • Reduced river navigability for barges • Roadside vegetation stress, reduces rainwater storages and increases soil erosion • Low stream and ground water flow
High Heat	Medium-low	<ul style="list-style-type: none"> • Pavement and rail buckling • Vehicles overheating • Electrical system malfunctions • Limitations on construction hours • Increase in extreme heat events (heat waves)
Wildfires	Low	<ul style="list-style-type: none"> • Road closures • Immediate and significant threat to human safety • Damage to roadside infrastructure • Increased risk of future flooding and slope failure
Severe Wind	Low	<ul style="list-style-type: none"> • Severe wind-related road closures • Blown-down trees, signs

Source: Minnesota State Climatology Office

Review of State DOT Resilience Practices

Resilience is the capacity of individuals, communities, institutions, businesses, and systems to survive, adapt, and grow, no matter what kinds of chronic stresses and acute shocks they experience. Shocks are typically considered single event disasters, such as fires, drought, and floods. Stresses are pressures that occur more frequently, such as earlier snow melt in the spring or more winter freeze/thaw cycles.

Leading state DOTs around the country are preparing for current and future climate changes. This planning process typically results in a resilience or adaptation plan. Sixteen states have a state-led climate adaptation plan, and more have efforts underway. State DOTs that were reviewed and interviewed about climate resilience and adaptation work include California, Colorado, Iowa, Massachusetts, Oregon, Utah, and Washington. See the Review of State DOT Adaptation Practices Report for full details. This work is summarized below.

The review of state DOTs effort related to climate resilience and adaptation was done in preparation for this report, and the key findings are summarized below. It is important to note that none of these DOTs had a position solely dedicated to climate resilience, and therefore the information reflected here may not be comprehensive.

Key Findings

The following resources could be used to inform MnDOT's approach to climate resilience:

1. Vulnerability Assessment – Several states have completed infrastructure vulnerability assessments and recommend this as a critical first state to understanding resilience (WA a good example).
 - a. A few states are developing ways to integrate climate risk into their risk assessments, either as a criticality input or in parallel with it.
 - b. IA is working to develop a Resilience Index, and in the meantime they are using a larger design event (200 year) for major highway bridges.
2. District Resilience Plans, California DOT – As part of a pilot, Caltrans created a district level climate change vulnerability assessment and adaptation plan. The plan includes a process for evaluating adaptation strategies into a districts prioritization and cost analysis.
3. State Adaptation Plan – A couple of the states have Adaptation Plans, and the DOT staff recommended supporting and participating in one, as it has helped advance their adaptation strategies.
 - a. [Example: Resilience framework](#) and system [diagram](#), Oregon – State level resilience planning documents that are used to advance climate adaptation work.
4. [Integration of Adaption and Resilience into Transit](#) (Southern California Association of Governments) – Presents the strategic approach used to integrate climate adaptation into SCAG work.
5. Resilience Hub – States indicated that having resilience/adaptation information centralized and shared widely helps advance the work more quickly and generates more opportunities for collaboration.
 - a. Resilience Clearing House, Mass – A statewide resilience repository of related documents and reports to centralize and streamline the ongoing efforts. Examples include: [Colorado](#), [Massachusetts](#), and [California](#).

For additional information about state and local adaptation plans, visit: [Georgetown Climate Center](#)

Current MnDOT Efforts

For MnDOT, resilience applies to planning, design, construction, operation, and maintenance of our transportation system and facilities. MnDOT’s existing and future assets will become increasingly stressed by climate change and extreme weather, particularly from projected precipitation increases and larger and more frequent storm events. The section below is broken down into program areas, and Table 2 provides an overview for each one.

Table 2: MnDOT Efforts that Build Resilience to Climate and Extreme Weather by Program Area

Program Area	Examples
Planning	Slope Vulnerability Assessment and Stabilization Guide, Extreme Flood Vulnerability Assessment
Design and Environmental Review	Aquatic Organism Passage Guide, consider of geomorphic design in floodplain culverts
Construction	Storm water and erosion control to protect assets, 2014 Flood Mitigation Program
Maintenance & Operations	Response salt management program, native and resilient plants
Emergency Response	State Aid betterment, Emergency Relief

Planning

Flash Flood Vulnerability and Adaptation Assessment Pilot Project (2014)

Completed in 2015, this [assessment reviewed MnDOT](#) bridges, large culvert, pipes, and roads paralleling streams in District 1 and District 6 for vulnerability to increased flooding. The project included a facility level adaptation assessment that modeled the costs and benefits of various design options under different greenhouse gas emissions scenarios.



Figure 4: Flood waters washing out road in District 1

MnDOT was one of [19 Climate Resilience Pilot projects](#) selected by the Federal Highway Administration (FHWA) as part of an effort to evaluate the FHWA Climate Change & Extreme Weather Vulnerability Assessment [Framework](#). The study created a useful framework for how to analyze projected risks from climate change and it set the stage for the agency to learn more about infrastructure resilience and risk. The insights gained from this project created the foundation for the follow-up Extreme Flood Vulnerability Analysis (listed below). Figure 4 shows an extreme flood event where the road adjacent to a bridge washed out.

Extreme Flood Vulnerability Analysis (2019 – Ongoing)

The Extreme Flood Vulnerability Analysis will address the challenge of increasing and non-uniform extreme flood events by developing a methodology to characterize the vulnerability of MnDOT bridges, large culverts, and pipes to flooding. This effort will build on the Flash Flood Vulnerability and Adaptation Assessment Pilot Project. It will develop and test ways to enhance the vulnerability scoring techniques used to ensure their applicability

throughout the state. The current project will not actually do a statewide assessment, but instead specify an approach that could be used. This project will also explore how the analysis can be incorporated into the state's asset management systems. The results of this work will provide a clear path for MnDOT to prioritize adaptation actions; a key step towards enhancing agency resilience and maintaining good fiscal stewardship.

Slope Stabilization Guide (2017)

[This user guide](#) provides simple, cost effective methods for stabilizing locally maintained slopes along roadways in Minnesota. Eight slope stabilization techniques are presented that local government engineers can use with locally available materials and equipment. The recommendations are based on input from MN county engineers, case studies from site investigations within the state, and slope stability analysis (including limit equilibrium methods). This guide can be used with and to further inform the slope assessments (below).

Slope Vulnerability Assessment (2019)

Minnesota's climate, geomorphology, and steep terrain along rivers increase the incidence of slope failures such as rock-falls and landslides. The goal of the [slope vulnerability assessment](#) was to determine the risk of slope failure along state highways in Districts 6, 7, and the Metro District. The report includes a new GIS model that can be implemented anywhere in the state.



Figure 5: Example of a failed slope along a MnDOT road

The model contains three main parts:

- 1.) Identify past slope failures
- 2.) Model the causative factors of past slope failures and how they vary locally
- 3.) Model the risk of new slope failures

Vulnerability factors including slope, terrain curvature, proximity to rivers, and proximity to bedrock outcrops were statistically tested to determine their capabilities in causing slope failure (Figure 5). Field verification results validate the model's capability of identifying risk in regions with different geology, geomorphology, and hydrology. Model results were ranked into four risk management categories: action recommended, further evaluation, monitoring, and no action recommended. Risk incorporates the model outputs with consequence to infrastructure including distance to roads and populated areas. Results indicate that 826 of the 35,000 management areas studied are recommended for mitigation. Next steps include field visits and a site-specific mitigation program. Knowing where the most vulnerable slopes are allows MnDOT to prioritize them and reduce the risk of failure and public safety.

Phase 3 (Final) Slope Vulnerability Assessments (2019 – Ongoing)

Slope failures can cause millions of dollars in damage and clean-up costs, harm or threaten lives and property, have significant negative environmental affects, and create lengthy detours. Recent research has advanced our understanding and improved our modeling capacities to identify vulnerable slopes before slides happen. Next steps included implementing the model in all remaining Districts (1, 2, 3, 4, and 8). To that end, this scope of work covers [Phase 3 of the](#)



Figure 6: Example of a slope along a MnDOT roadway

[modeling for the remaining counties](#). Figure 6 shows a slope above the roadway – if unstable the slope can threaten road safety and access.

Design and Review

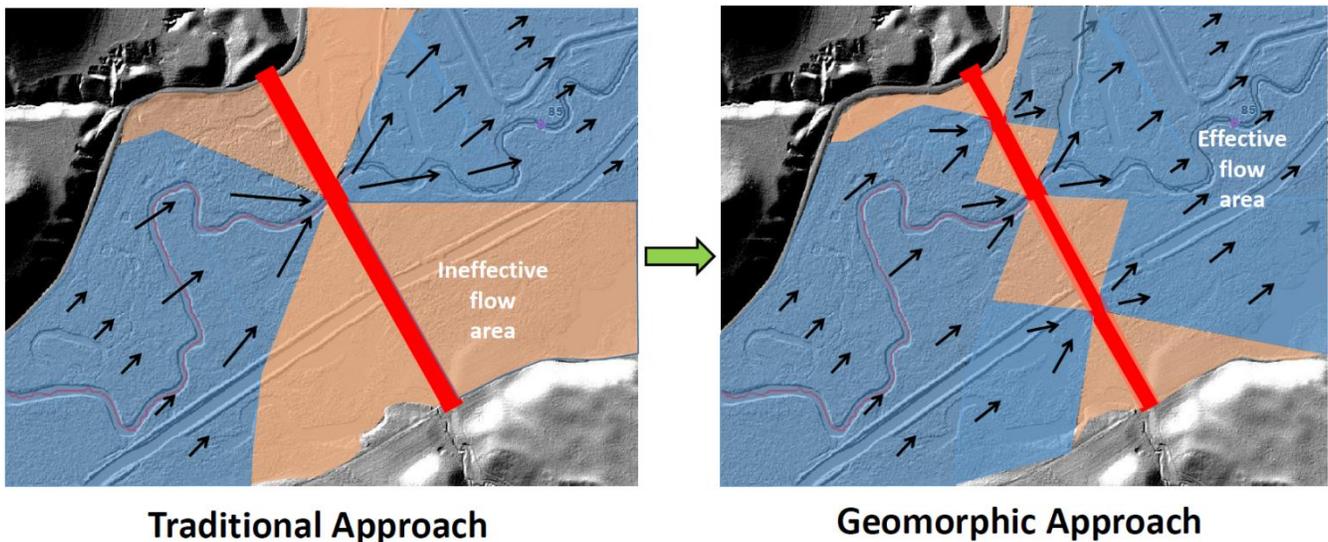
MN Guide for Stream Connectivity and Aquatic Organism Passage through Culverts (2019)

Culvert design improvements that benefit aquatic organisms have the added benefit of improving culvert resilience to climate change impacts (e.g. energy dissipation, sediment transport, etc.). It is a [thorough guide](#) for culvert designers, hydraulic engineers and others involved in culvert design and construction in Minnesota. “Using results from previous MnDOT research studies and consultations with experts, researchers developed a guide for culvert design that promotes the safe passage of fish and other aquatic organisms as well as stream connectivity throughout the state. These changes in design have several benefits, including reducing designs that likely to lead to roadway damage and need for repairs.” (quoted from the guide)

Geomorphic Design

[Geomorphic Design](#) is a strategy to reduce flooding and infrastructure failure by adding flood plain culverts in lieu of expanding or increasing bridge culvert size. MNDNR and MnDOT are discussing a partnership to deploy this approach in several locations. The approach does not make sense in all cases, depending on soil type, floodplain size, etc. Using geomorphic design can increase waterway connectivity, design channel sedimentation, and reduce the risk of overtopping. Additional information is needed about its efficacy and the cost tradeoffs. Figure 8 below depicts a simplified example of the flood benefits of adding additional culverts along a river floodplain.

Figure 7: Overview of Traditional VS Geomorphic Design Approach



Construction and Implementation

Stormwater – Erosion Control

Erosion control increases resilience as the risk of repair or rebuild before end of life is reduced, and the burden on the storm water system is reduced (i.e. help maintain capacity). The MnDOT [Environmental Stewardship Office](#) works with design, construction and maintenance project managers to develop plans and procedures that promote cleaner project sites, and to protect the waters of the state during construction and maintenance activities. Sediment control, especially permanent features, could infiltrate water or mitigate peaks so there is less flooding, though it does not increase infrastructure capacity.

Statewide Flood Mitigation Program (2014)

The \$50 million statewide flood mitigation program helps make state roadways more resistant to future flood damage. The program was created after substantial statewide flooding in fall 2010. It results in lower costs to repair damage from future floods and a more sustainable transportation system. It also provides more value and safer communities to Minnesotans with reduced repair costs and less traffic disruption.

The [flood mitigation projects](#) were funded through existing bond authority and include:

- Improvements to drainage structures, slopes, berms and ditches prone to flooding
- Repairs, realignments or raises to highways that regularly flood

Sustainable Pavement

MnDOT is increasingly using sustainable asphalt pavements as a way to reduce costs, reduce emissions, and increase durability. In 2018, MnDOT carried out 16 construction projects using full-depth reclamation or cold in place recycling. These pavement types help MnDOT adapt to climate change due to the increased durability.

Maintenance and Operations

Living Snow fences

Living snow fences help with climate adaptation by using natural systems to decrease the effects of extreme snow events, especially as they become more unpredictable, and therefore difficult to budget for. They also decrease the amount of snowplowing required to clear a road, while providing ecological benefits year-round. [Living snow fences](#) are trees, shrubs, native grasses and wildflowers located along roads or around communities and farmsteads (see example in the figure to the right). These living barriers trap snow as it blows across fields, piling it up before it reaches a road, waterway, farmstead or community. The use of living snow fences is increasing and they not only reduce the need for on-road snow removal, but also improve the adjacent air and soil quality.



Figure 8: Example of snow fencing along a MnDOT roadway

Salt Management

More ice is expected as Minnesota experiences warmer winters and precipitation patterns shift. More efficient salt use allows MnDOT to respond to these changes, while also decreasing costs and pollution, and increasing water quality. MnDOT salt reduction efforts include installing sensors on trucks, reviewing weather predictions to better estimate needs, and using snow fencing. The MnDOT [Salt Solutions Program](#) is a hands-on program that monitors and employs research on equipment, chemicals, and the training needed to successfully keep lanes clear in the winter. It includes but is not limited to pre-wetting, de-icing, anti-icing and sensible salting on the state highway system throughout the entire state, with emphasis on environmental effects and how to complete the work economically without sacrificing the safety of residents.

Native and Resilient Plants

Many trees and perennials planted today will mature when the climate looks different – that means MnDOT needs to be planting a mix of species that is not just what grows well now, but also able to thrive in the future.

The MnDOT Environmental Stewardship Office already has in practice the use of [native plants mixes](#) that are designed to be resilient to the changing climate (see picture of native plant habitat to the right). This includes the use of Integrated Vegetation Management – a roadside design and management strategy that restores native vegetation and allows roadside plant communities to evolve and mature over time, resulting in lowest lifecycle maintenance costs and maximum highway operation, environmental, and social values. Wildlife changes are also anticipated to increase the number of endangered species we have to manage (such as the Rusty Patch Bumble Bee).



Figure 9: Example of native planting habitat adjacent to the highway

On-site Solar Energy

On-site energy generation can be an important adaptation measure as it helps MnDOT facilities provide emergency power and be more self-sustaining. Solar energy projects increase resilience by supporting local energy jobs, long-term energy cost stability, and energy access in the event of a grid disruption (e.g. natural

disaster, etc.). Figure 11 shows the solar array on the roof of a MnDOT facility. The [overview of solar efforts](#) at MnDOT highlights how solar energy is being pursued.



Figure 10: Solar panels on the roof of a MnDOT facility

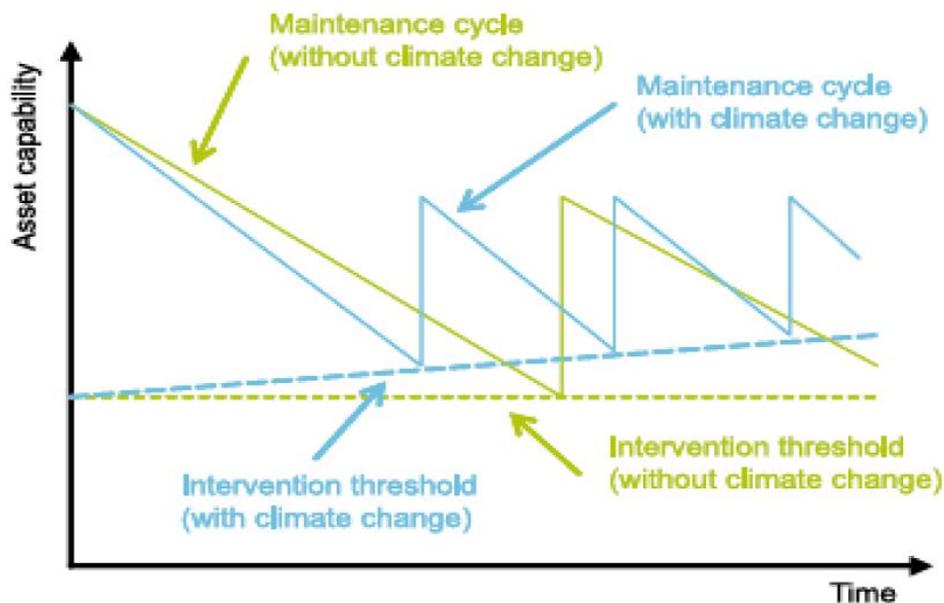
Asset Management

MnDOT uses BRIM (bridges and large culverts) and TAMS (highway culverts, pipes, and some additional infrastructure) to track asset condition and characteristics. Asset inventory tools like these are a critical part of climate resilience and adaptation, and make further adaptation and resilience efforts possible. In 2019, [Minnesota Statute 174.03 Subd. 12](#) required MnDOT to develop an inventory for geotechnical assets. Examples of geotechnical assets include retaining walls, slopes, and fencing systems. As MnDOT builds this inventory, there is an opportunity for the agency to consider which assets to track and how to use the data to increase system resilience. Figure 12 shows one way climate change is expected to impact infrastructure maintenance cycles, making it even more important to have accurate asset information. Incorporating climate change into an asset management system shifts both the intervention threshold and frequency of maintenance (for example due to more frequent and severe precipitation).

Figure 11: Maintenance Cycle with vs without Climate Change

Asset Management





UK Highways Agency, Climate Change Adaptation Strategy and Framework.

Emergency Response

State Aid Betterment Program

The state aid program helps build resilience by funding improvements (i.e. betterments) to infrastructure that has been damaged or destroyed. Supporting these improvements increases the climate adaptation of the infrastructure through resistance to more severe weather and flood events. Examples include increased elevation, reinforcing, bridge height, etc.

Emergency Management and Response

Currently Emergency Management includes emergency relief program and tracks the process throughout it. This covers in-kind replacement and betterment considerations, and a review of whether the rebuild/betterment violates or improves NEPA compliance. FHWA, FEMA, and State Disaster Fund are the 3 main sources of funding, and the latter 2 have notably different criteria from FHWA.

Gaps and Opportunities

This section describes opportunities for MnDOT to increase resilience in the transportation system. It was developed based on MnDOT’s current practices, conversations with staff, and a review of adaptation best practices from FHWA and other DOTs. MnDOT staff are already working to advance many of these opportunities, and so things will change as efforts progress and new information is available.

Climate change is exacerbating stressors that already exist and increasing the vulnerability of people and assets. Table 3 provides an overview of the climate resilience opportunities presented in this section. Understanding vulnerability to climate change is the first critical step to taking action, which includes understanding infrastructure vulnerability and social vulnerability. As better data becomes available, the agency needs to be in a position to use it to improve resilience.

Table 3: Overview of Efforts to Advance Climate Resilience

Action	Status (Leads)	Action Description
Complete system-wide climate vulnerability assessment	In Progress (Bridge, OSPH)	Develop a set of climate projections and use to assess infrastructure vulnerability (where applicable)
Incorporate climate vulnerability findings into asset management systems	Planned (Bridge, OSPH)	Integrate findings of the vulnerability assessments into asset management, if possible (BRIM and TAMS)
Use research results to review and update Drainage Design Guidelines	Planned (Bridge)	Review drainage design guidelines using use climate research to determine when and how to consider evaluation of resiliency
Advance initiatives that indirectly increase resilience	In Progress (OTSM, OSPH)	Reduce impacts to environmental justice and vulnerable populations, increase alternative fuels infrastructure
Incorporate more resilience in Emergency Response/Repair	In Progress (Bridge, State Aid, OSPH)	Establish a standard practice that ensures MnDOT can use appropriate hydrology to size and design infrastructure damaged by extreme events
Support development of downscaled statewide climate data	Not started (OSPH)	MnDOT should continue to support the development of a downscaled climate data set to improve forecasting and resilience analysis.
Develop actions with adaptation co-benefits	In Progress (OSPH)	Identify, support, and pilot projects with potential to increase resilience (e.g., slope vulnerability)
Lead resilience research	In Progress (Bridge, OSPH, others)	Continue to develop state specific research projects to address data and information gaps (e.g., understand changes in freeze/thaw cycles)

The first 3 actions of Table 3 focus on infrastructure vulnerability and risk reduction. Using qualitative assessments, check storms, or climate change projections to assess infrastructure vulnerability will allow MnDOT to better

understand risk: both of existing infrastructure (via asset management) and future infrastructure (via design standards). This new information can then be used to inform how and what infrastructure is prioritized for resilience measures.

As part of this process social vulnerability could be factored in (such as via criticality, project-adjacent residents, transit use, etc.) to ensure the infrastructure being prioritized for resilience is equitable (see the 4th action: Advance initiatives that indirectly increase resilience). MnDOT needs to continue to develop how it defines and measures social vulnerability, as the people most vulnerable to climate change are often those already most impacted by environmental and social stressors. Though climate adaptation is not the reason driving MnDOT's equity work, increasing transportation equity will have the added benefit of improving community resilience.

The gaps and opportunities noted here are interconnected and will continuously inform each other. For example, as better climate projections become available, it could change the anticipated impacts in a region. Therefore as MnDOT develops processes and policies for climate adaptation, they should be designed to incorporate new data as it becomes available.

In reviewing this section it is important to note two things.

- 1) These are all intended to fit into the existing processes at MnDOT.
- 2) Climate adaptation is not a separate part of our work, but rather another way of thinking about what we are already doing.

Figure 12: Example of Agency Objectives for Building Climate

- **Objective 1 - Identify critical assets and routes**
- **Objective 2 - Integrate climate change forecast data [where appropriate]**
- **Objective 3 - Provide an actionable climate adaptation and resilience strategy**
- **Objective 4 - Increase transportation system disaster recovery and resilience**
- **Objective 5 - Support local planning efforts**

Figure 12 is an example of Agency Climate Resilience Objectives adapted from the [Southern California Association of Governments](#). For each one of these objectives they developed a series of actions. It is an example of where MnDOT could go following this report. Establishing a set of agency objective or strategic goals will be an important step in determining how to prioritize the opportunities below. They could help direct the efforts of the agency and ensure MnDOT is working strategically towards the desired outcomes.

Finally, a valuable resource worth noting is the FHWA *11-Step General Process for Transportation Facility Adaptation Assessments*, which is a framework for assessing facility climate vulnerability. The full framework is outlined in Appendix A and is a great resource for evaluating a site.

Build Climate Resilient Infrastructure Part 1

Select Climate Projections, Assess Climate Vulnerability

MnDOT uses the precipitation frequencies in Atlas 14⁴ to develop and validate design standards. Unfortunately, climate change is happening quickly in Minnesota and increasing the rate at which this dataset becomes outdated. To ensure infrastructure will last as long as planned, MnDOT needs to account for future climate conditions in asset management and design guidelines. Given the uncertainty created by climate change, this can be difficult to do, especially for infrastructure with low frequency design events (e.g. 100 year event). Therefore a suite of tools will be needed to build infrastructure resilience. To develop these tools, one of the first steps is to select climate projection data that MnDOT is confident in. The agency then plans to develop formulas for assessing infrastructure vulnerability using the projected precipitation frequencies. The goal is to use the output and formulas in the follow up actions in Part 2.

Why

MnDOT designs infrastructure to last a specific amount of time and to an acceptable level of risk. Having new precipitation and vulnerability data will allow MnDOT to be confident it will be able to continue to do so into the future.

Barriers

- MnDOT will not necessarily select a single set of projection estimates to replace Atlas 14, and there is no clear guidance from FHWA.
- There are no accepted industry standard practice on how to select climate projections.
- New precipitation data would create a need to update procedures, materials, and providing trainings.

Example of how to select future precipitation (e.g. for use as a check storm)

- Project out current weather patterns, create a trend line to look at what a 10% annual probability flood event would be in 50 years and then design for that. One analysis calculated that a 10% annual flood event in 50 years will be equivalent to a 68 year flood event today.
- Use Atlas 14 90% Confidence Intervals: Hennepin County is reviewing flood projections in partnership with the University of Minnesota, City of Minnetonka, Minnehaha Creek Watershed, and MnDOT. They are proposing to the county leadership that the county adopt flood design standards that reflect the high end (90% confidence interval) of what is in Atlas 14. An example would be switching the 100 year/24 hour precipitation from approximately 7.5 inches to 9.5 inches.

Opportunities for MnDOT

- Increasing climate preparedness will reduce risk to public safety and reliability as extreme weather events get worse.
- Provide information to make design standards more climate ready, reducing medium and long term costs, even as climate chaos and extreme weather events cause failures and damage beyond what is currently observed.
- Create and implement a new standard practice at MnDOT to lower barriers to adoption and streamline uptake statewide. Also provides guidance that local governments can consider and use as applicable.

⁴ Atlas 14 is the NOAA publication that serves as the official government source of precipitation frequency values

Next steps

- OPSH continues to support the Extreme Flood Vulnerability Assessment that is developing a set of climate projections used by MnDOT where appropriate.
- Develop and test methodologies for evaluating resilience in infrastructure analysis and design.

Build Climate Resilient Infrastructure Part 2

Incorporate Vulnerability Assessment Findings into Asset Management and Review Design Guidelines

Why

With improved understanding of future precipitation patterns, MnDOT can evaluate existing processes and develop tools to reduce climate risk. Two opportunities are to evaluate the feasibility of incorporating flood vulnerability into asset management decisions, and review current design guidelines to determine when and how to incorporate climate resilience and vulnerability (following results of Part 1 and related research projects). Different aspects of design will be impacted disproportionately, so it is important to understand what can be done now and where gaps in data, process and methodology remain. This will help more accurately inform how MnDOT critically evaluates cost/benefit and risk tolerance.

Barriers

- Not all co-benefits can be clearly included in MnDOT models (e.g. benefit of avoided reconstruction to ecosystem, etc.), this underestimates benefits of improved resilience.
- It will cost more to design some projects to higher standards.
- MnDOT has not determined or prioritize the sections of the design guidelines to update ([see list of sections here](#)).
- There is a great deal of uncertainty and variability in the climate models.
- No accepted methodology for appropriately using climate model results in hydraulic design.

Examples of other agency approaches

- NYC created [resilience design guidelines](#). For example, roads, highways and bridges should adjust design requirements for all infrastructure built to last more than 20 years to use the 100 year flood estimate for 2050 instead of the current 100 year flood event.
- WSDOT provides a guide for incorporating climate change [into planning](#) and [into projects](#) for NEPA and SEPA environmental documents, based on a statewide vulnerability assessment.
- After a series of severe floods the Iowa DOT has unofficially adopted the policy of using the 200 year flood for highway design in place of the 100 year flood event. At least until FHWA provides better climate guidance.

DISTRICT ADAPTATION PLAN

Caltrans developed a climate adaptation plan for their District 1, which laid out a process for determining the most strategic adaptation action. The process includes climate impact, criticality of infrastructure, vulnerability, a review of potential adaptation options, criteria for ranking adaptation options, and a ranked list for each county.

Next steps

- Bridge Office: Drainage Manual - Although the current MnDOT Drainage Manual does not address climate change, there are plans to introduce options for considering resilience and adaptation during designs in the next edition of the manual.
- Incorporate results of the Extreme Flood Vulnerability Assessment into the BRIM and TAM systems (timeline TBD depending on approach).
 - Determine how to weigh future climate vulnerability in the asset management systems, and develop training as needed.
- Form a team to review design alternatives and make recommendations on how to use precipitation projections in MnDOT designs and programs, when they should be applied, and what adaptation practices to consider. The team would consider the outcome of Part 1 above and other research such as NCHRP 15-61 and NCHRP 20-44(23), which are producing and piloting a design guide for use of climate model data in hydraulic design.
- Work with FHWA to organize peer exchange on corridor vulnerability assessment (early 2020).
 - Pilot Corridor Assessment focused on increasing the resilience of trunk highway projects.
- Discuss new ways to incorporate resilience in the investment direction developed during the next update to MnSHIP. See current investment direction [here](#).
- Future Step: Analyze/model cost implications of changes to design and construction.
 - Example: Do case studies to compare costs and long-term tradeoffs for different designs.



Figure 13: Washout of a MnDOT roadway

Advance Initiatives that Indirectly Build Resilience

Reduce Impacts to Environmental Justice and Vulnerable Populations

Having a transportation system that is more inclusive, accessible, and equitable increases community resilience, and is especially important for reducing the vulnerability of those least able to absorb and recover from the impacts of climate change. Similar to infrastructure, MnDOT needs to better understand who is impacted, how, and where they are, and how transportation can reduce their climate vulnerability. Unlike infrastructure, this area is less developed, though not less important.

MnDOT has already begun focusing on this through the Office of Equity and Diversity and efforts to improve what outcomes are measured. Part of this effort includes the MnDOT reports for each district that highlight the census tracts with above state-average number of vulnerable populations adjacent to planned projects. This is a great tool and provides valuable context and information for communications, planning, public engagement, and project design. In 2017 MnDOT launched the [Advancing Transportation Equity](#) initiative to better understand how transportation systems, services, and decision-making processes help or hinder the lives of underserved and underrepresented communities in Minnesota. **Though climate adaptation is not the driver of MnDOT's equity work, increasing transportation equity will have the added benefit of improving community resilience.**

Barriers

- Is difficult to define and measure social vulnerability in a way that can be factored into MnDOT practices (e.g. criticality measures, etc.).
- The connection of equity and transportation infrastructure is less direct and the impacts need to be more clearly linked.

Opportunities

- MnDOT can work to incorporate the increased adaptive capacity of best practices to more directly capture the benefit to vulnerable populations (e.g. Complete Streets, etc.).
- Develop better measures of equity to support decision-making and funding decisions.

Next Steps

MnDOT can work to increase the use of social vulnerability information in decision-making, and better understand how the district EJ reports were used and can be improved upon. Ultimately better data could support MnDOT in taking actions that help reduce impacts to environmental justice communities.

- Provide Districts additional guidance on how social equity and vulnerability data/reports can be used during the planning and design phase of projects. Speak with the team that develops the reports and the district offices that use them to identify potential improvements.

SOCIAL VULNERABILITY REVIEW

FHWA has noted that disruptions have a greater impact on vulnerable populations. A review of human vulnerability in DOTs showed there is not a consistent definition or approach to incorporating it. Several organizations and DOTs have developed social vulnerability indexes (e.g. ACE) and work to factor them into the planning and decision-making process.

- Work with MnDOT internal team to build a more complete social vulnerability dataset **to inform decision-making on where and when to invest in adaptation. Reducing vulnerability of certain populations can have greater benefits system-wide than equally spreading projects.**

Active Transportation and Complete Streets

Active transportation, transit, and complete streets help Minnesota be more prepared for and adapt to a future where climate impacts will be more severe and more frequent. A diversified and robust transportation system helps ensure a safer and faster recovery for everyone. The [MnDOT Complete Streets](#) policy is an approach to road planning and design that considers and balances the needs of all transportation users. To improve the safety and functionality for all users. The figure to the right is an example of wider sidewalks combined with parking. This approach helps build resilience through increased transportation diversity, community connectivity, increased health and mobility, decreased pedestrian death and injury, and increased awareness among planners of who the users are of the space and how to design for them.



Figure 14: Example of Complete Streets sidewalk and parking alternative

Electric Vehicles and EV Infrastructure

Diversifying alternative transportation fuels and associated infrastructure has been shown to increase the speed of disaster recovery ([see NREL report](#)). Though climate mitigation is often the driving reason, it is worth mentioning vehicle electrification as it helps MN be prepared for the coming changes. EVs are expected to quickly become a significant part of the transportation system and MnDOT is adapting to that reality by laying the infrastructure now (see example of corridor signage to the right). [Accelerating Electric Vehicle Adoption: A Vision for Minnesota](#) is the first coordinated attempt to outline a statewide vision for increasing EV use to 20% EVs by 2030.



Figure 15: Signage for highway with Electric Vehicle charging infrastructure

Building Rural Climate Resilience: The Role of MN State Agencies (2019)

Efforts to address climate adaptation and resilience in rural areas are critical to strengthen the resilience of the entire transportation system. [The Building Rural Climate Resilience report highlights](#) many ongoing efforts throughout the state as well as a large list of available funding sources from state agencies.

Incorporate more Resilience in Emergency Response/Repair

Why

When making the investment to improve infrastructure certain adaptation measures can significantly improve its resilience. These reduce the likelihood that MnDOT will have to rebuild a facility before the end of its intended lifespan. Though this has not yet been an issue for MnDOT, others have had challenges doing it. The best policy to address this could change based on the results of the Extreme Flood Vulnerability Assessment (see above). Therefore it may be worth waiting until the assessment is complete before finalizing a policy on this.

Barriers

- No guidance/policy in place on how to use climate projects, and requires getting the approval of FHWA.

Examples of how

- District 1 used the existing climate vulnerability score and ranking to help justify using rebuild funds to upgrade the facility. (Highway 23 S. Fork Nemadji River DDIR)

Opportunity

- Establish a standard practice that ensures MnDOT can use precipitation projections to justify the rebuilding of a project with improvements.

Next Steps

- Develop a policy based on current climate assessments, once the Extreme Flood Vulnerability Assessment has completed that part of the project (early 2020).
 - Once complete, work with State Aid, Bridge Office, and FHWA on improving the use of and acceptance of “betterment” to include additional resilience improvements (based on projections).

Support Development of Downscaled Climate Data

The State Climatology Office provides MnDOT with state-wide climate data. MnDOT would benefit from more data on local climate impacts (i.e., “downscaled”) to better understand and anticipate impacts on transportation infrastructure in different regions throughout the state. The high level climate projections are not detailed enough to use for certain needs, such as hydraulic design, but a model with smaller spatial scale (4km for example) would allow for better planning.

Why

This data analysis would generate more accurately projected regional climate changes and allow MnDOT to make more informed decisions (e.g. better understand expected changes to “benchmark” events, such as 24hr/50 year precipitation or 24hr/100 year precipitation).

Barriers

- MnDOT is not in a position to support/fund this work directly.
- Updated model and outputs will take 1-3 years to develop before they can start to be used.
- Downscaled data needs to be statistically analyzed and provided in a format that can be used by MnDOT.
- Climate models are updated regularly and downscaled data would need to be redone.

Next Steps

- Continue to support the state providing funding for this, and share how it would help improve current practices at MnDOT. Example: MnDOT sends a letter of support to U of M, legislature, etc.
- Speak with MnDOT staff to get specific examples of how more accurate downscaled climate data would help.

Develop Actions with Adaptation Co-Benefits

This section contains projects and ideas that are still being developed, and have been identified as having potential for adaptation benefits. They are very much a work in progress.

Increase compost in soil fill and other projects

- *What:* Using compost on projects instead of top soil or sand can have many benefits. MnDOT already has specs for compost use. See stats and cost below.⁵
- *Why:* Using compost over top soil can sequester carbon, reduce erosion and stormwater runoff, and increases water quality. The difference is 5-7% carbon sequestration versus 1%, and the compost would reduce stormwater runoff (absorbs 8x the amount of water) and filter better.
- *Barriers:* Compost is more expensive, and distribution centers are limited (i.e. has to be hauled long distances). Some of the co-benefits of use are still unquantified.
- *Next Step:* Track ongoing research projects and develop a way to capture the adaptation benefits from compost use (carbon sequestered, vulnerability reduction, etc.). Determine the amount we are currently using, and what percent of the total it is.

Vegetation co-benefits (slope stabilization and reduced runoff)

- *What:* Vegetation has the ability to hold soil in place when properly rooted and absorb more water and nutrients.
- *Why:* To increase soil stability, and reduce stormwater and nutrients runoff.
- *Barriers:* Increases costs of initial planting. All the co-benefits have not been incorporated into MnDOT practices, and some of the benefits are not gained directly by MnDOT.
- *Next Steps:* Develop a case for considering vegetation as part of the infrastructure – compile case studies/examples, and pilot a project in MN. MnDOT could also A) include more landscape architects during the design phase, and B) Require the oversight of a trained plant expert during larger projects.

There are many other actions that help build climate resilience as a co-benefit – this list is not comprehensive, and does not include ones that are already in practice (such as those in the Current Practices section).

⁵ \$40/ton CO₂e, 4lbs CO₂e per 1 mile a truck has to haul, 27lbs CO₂e/1ft/1ft in compost soil, and 150lbs CO₂e in avoided methane from landfill

Potential Research Questions

- How has the freeze/thaw cycles across Minnesota changed for the last few decades with climate change and warmer winters? (funding pending)
- Research the benefit of having vegetation at the top of the bluff, and compare tradeoffs versus co-benefits. Is there any existing research showing how this does (or doesn't) improve stability and reduce maintenance?
- Could the bridge planning index used in MnDOT's Bridge Replacement and Improvement Management System include new resilience related vulnerability metrics?
- What is the benefit and potential of more strategically using wetland banking to reduce the vulnerability of infrastructure? (see posted research question)

To share additional comments and ideas, or reach out with questions contact: Jeffrey Meek (jeffrey.meek@state.mn.us)

Conclusions and Next Steps

Minnesotans are feeling the impacts of climate change and without additional adaptation efforts Minnesota residents could be at further risk. MnDOT's current efforts to address climate adaptation and resilience are numerous and make the agency one of the leaders among DOTs nationally (see *Review of State DOT Adaptation Practices Report* for more detail). MnDOT is conducting an analysis of how projected climate will impact bridges, pipes, and culverts (via projected extreme flooding), and is developing social vulnerability reports for each district to inform decision making and outreach for MnDOT projects. To mitigate the increased risks that climate change brings, a suite of resilience tools should be developed and along with guidance on how and when to apply them. Use of these resilience tools will need to be balanced with other critical factors such as cost, safety, capacity, and environmental impact to select the best adaptation response (e.g. enhance, defend, accommodate, or retreat). This report highlights the need for data driven analysis that identifies the best ways forward to build the case for incorporating climate adaptation action to mitigate risk.

Through review of materials and discussion with staff the following key actions have been identified to further ingrain climate adaptation work into MnDOT practices. The actions highlighted in the Gaps and Opportunities section help MnDOT understand where to focus its climate resilience efforts, with the goal of developing a suite of resilience tools for the agency. To properly address climate impacts and deploy adaptation strategies additional funding may be needed.

Summary of next steps

- Complete the Extreme Flood Vulnerability Assessment and use climate projections to evaluate infrastructure vulnerability.
 - Develop process for incorporating the findings into BRIM and TAMS
 - Review Design Guidelines: evaluate current design guidelines and identify where and how climate projections should be considered.
- Improve the use of social vulnerability in decision making around adaptation strategies.
 - Gather feedback on the district environmental justice reports.
 - Establish Social Vulnerability metrics that are consistent and inclusive, and develop guidelines to use them in selecting resilience tools.
- Pilot a corridor level resilience assessment.

The steps above help MnDOT build a toolbox of resilience strategies and prepare the agency for the projected changes. As strategies are identified additional research, pilots, and analysis will be needed, such as an evaluation of the cost difference and other tradeoffs of building infrastructure with different resilience tools. MnDOT already has a strong foundation to build on and through strategic efforts can further increase the resilience of the transportation system.

Appendix A

FHWA 11-Step General Process for Transportation Facility Adaptation Assessments

The project team developed the 11-Step *General Process for Transportation Facility Adaptation Assessments* (the *Process*). The *Process* is intended to be general enough to be applied to multiple transportation modes and asset types, both existing and proposed facilities, and various climate stressors. The 11 steps are:

1. **Describe the Site Context** - Describe location-specific details to characterize the broader transportation network and the surrounding environmental, economic, and social context.
2. **Describe the Existing / Proposed Facility** - Describe facility-specific details.
3. **Identify Climate Stressors that May Impact Infrastructure Components** - Identify climate-related variables that are typically considered in planning and design of the facility type.
4. **Decide on Climate Scenarios and Determine the Magnitude of Changes** - Describe climate model projections that are used.
5. **Assess Performance of the Existing / Proposed Facility** - Assess whether the facility is performing as expected under current climate data and design assumptions and whether it will continue to do so under each of the possible future climate scenarios.
6. **Identify Adaptation Option(s)** - Identify potential adaptation options that could be used to address climate risks to the facility.
7. **Assess Performance of the Adaptation Option(s)** - Assess the performance of each adaptation option under each potential climate scenario.
8. **Conduct an Economic Analysis** - Evaluate how the benefits of undertaking a given adaptation option compare to its incremental costs under each of the possible climate scenarios.
9. **Evaluate Additional Decision-Making Considerations** - Identify and evaluate other factors that should be considered before a final decision is reached.
10. **Select a Course of Action** - Consider both economic and non-economic factors, weighing all the information presented, and select a course of action.
11. **Plan and Conduct Ongoing Activities** - Identify, plan for, and conduct ongoing activities.

The project team piloted the *Process* across a range of transportation asset types and climate change stressors. Each of the 11 case studies of assets followed the same general 11-Step *Process*, with the specific of the methodologies tailored to each asset-stressor combination.

Source: [The Gulf Coast Case Study found on the Federal Highway Administration's resilience webpage](#)