

# MnDOT Flash Flood Vulnerability and Adaptation Assessment Pilot Project



## EXECUTIVE SUMMARY

NOVEMBER 2014

This document is part of a series of short reports based on the full Flash Flood Vulnerability and Adaptation Assessment Pilot Project.

This report was developed by the Minnesota Department of Transportation in accordance with a grant from the Federal Highway Administration (FHWA). The statements, findings, conclusions and recommendations are those of the author(s) and do not necessarily reflect the views of FHWA or the U.S. Department of Transportation.

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## EXECUTIVE SUMMARY

The Minnesota Department of Transportation takes flooding seriously. Flooded roads are unsafe, require detours, and compromise travel reliability. When planning road improvements, MnDOT planners and engineers have traditionally assumed that future conditions will be similar to those of the past. Climate change requires new approaches to understanding vulnerabilities in the transportation system so that risks can be minimized.

This project, one of 19 Federal Highway Administration (FHWA) climate vulnerability pilot studies nationwide looking at the effects of climate hazards on the transportation system, represents a starting point for developing these new approaches. The focus of this study is flooding risks to the highway system from heavy rainfall events. Flooding is not the only threat to the state's highway system posed by climate change; but it is likely to be one of the most significant and has already caused extensive disruptions in many areas.

The project focused on two MnDOT Districts that have experienced severe flooding in recent years: District 1 in northeast Minnesota and District 6 in southeastern Minnesota. District 1 experienced serious flooding in June 2012 when nearly 10 inches of rain fell on the Duluth area over two days. This resulted in numerous road closures and \$75 million in damage to the trunk highway system. District 6 has seen repeated flooding over the past decade with major events occurring in 2007, 2010, and 2012. Nearly nine inches of rain fell on the town of Cannon Falls in 2012, setting a new 24-hour rainfall record for the state.

A system-wide flash flood vulnerability assessment was conducted for the entire trunk highway network in both districts. Following this, one vulnerable facility in each district was selected to serve as a case study on how cost-effective decision-making can be made in the context of a changing climate.

The goals of this study were to:

- Better understand the vulnerability of the state's trunk highway system (interstates, US routes, and state roads) to flash flooding events
- Develop a process to identify cost-effective planning and design solutions to increase resiliency
- Support MnDOT's asset management planning efforts
- Provide feedback to FHWA on the assessment process





## System-Wide Vulnerability Assessment

The system-wide vulnerability scoring was conducted in accordance with the definition of vulnerability offered in the FWHA Climate Change & Extreme Weather Vulnerability Assessment Framework<sup>1</sup>. FHWA defines vulnerability as including three components (see Figure 1):

**Exposure:** The degree to which an asset may be affected by a climate stressor.

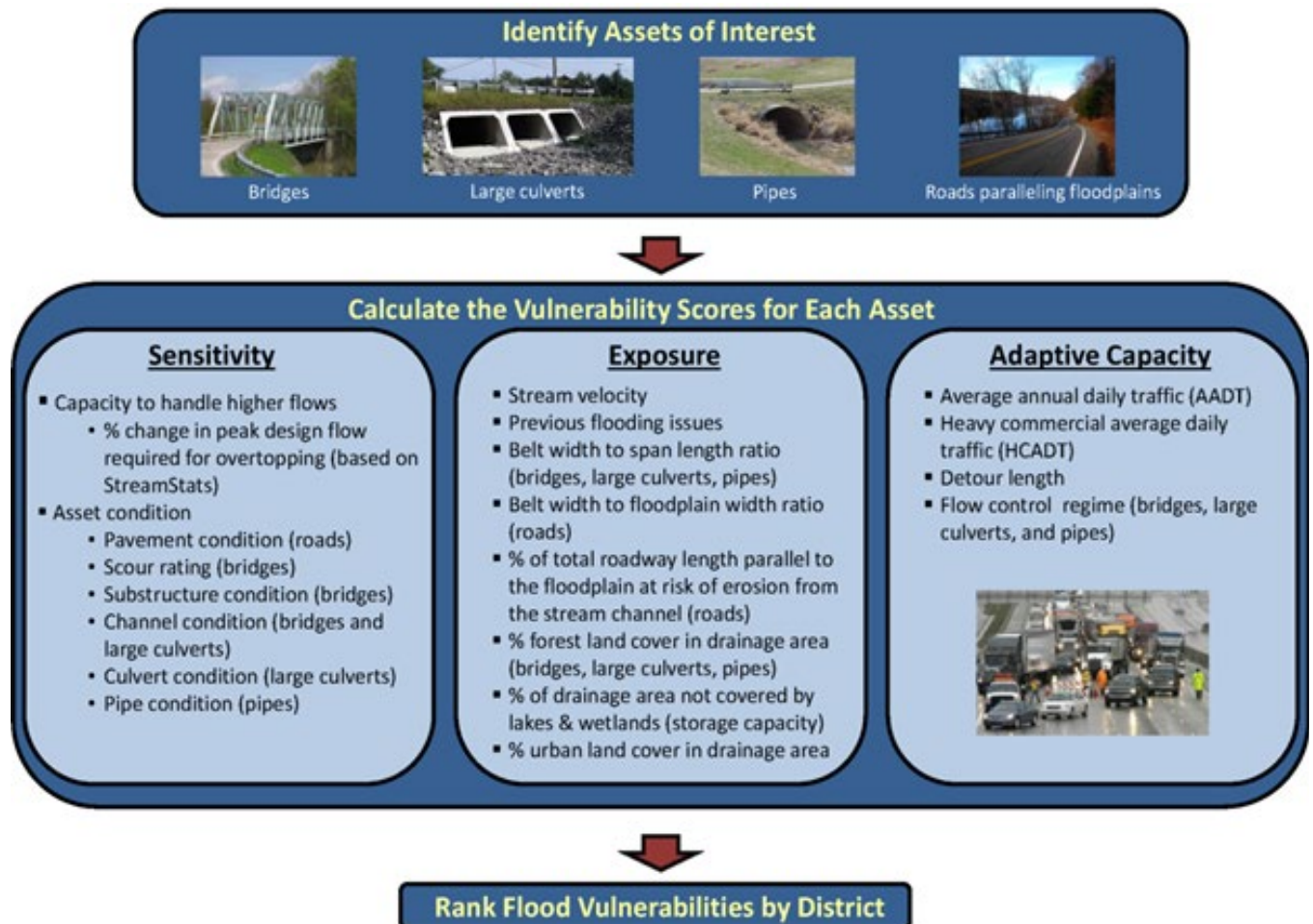
**Sensitivity:** How well an asset impacted by a climate stressor is able to cope with the impacts.

**Adaptive Capacity:** How resilient the transportation system as a whole is if the asset were to be taken out of service.

The state's trunk highway system was the roadway network selected for analysis in each district. The trunk highway system comprises the entirety of the state owned and maintained road infrastructure and includes all interstates, US routes, and signed state roads.

The highway system is comprised of a number of different asset types that are susceptible to flooding. Table 1 displays the asset types that were included in this assessment.

Figure 1: Approach to Flood Vulnerability Analysis



1: [https://www.fhwa.dot.gov/environment/climate\\_change/adaptation/publications\\_and\\_tools/vulnerability\\_assessment\\_framework/](https://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/vulnerability_assessment_framework/)

Table 1: Assets Included in Study

	Bridges	Large Culverts	Pipes	Roads Paralleling Streams
District 1	140	160	543	18
District 6	176	361	377	44

Each of these 1,819 assets was given a separate vulnerability score in the assessment. Note that slopes were also identified as being susceptible to heavy precipitation events but the project budget did not allow for their inclusion in this study.

Dozens of metrics were developed in order to quantify each facility's vulnerability. Each asset type has a unique set of metrics tailored to the factors important to understanding its vulnerability. For example, scour ratings are important to understanding the sensitivity of bridges to flooding but are not relevant to pipes.

Information gathered from the metrics was then combined into a single vulnerability score for each asset. Each metric was assigned a weight so that those metrics perceived as being more important to characterizing vulnerability could be factored more heavily into the final scores.

As the differences between individual scores may be within the margins of error involved in the analysis, five tiers of vulnerability were developed:

- Tier 1: Highest vulnerability
- Tier 2: High vulnerability
- Tier 3: Moderate vulnerability
- Tier 4: Low vulnerability
- Tier 5: Lowest vulnerability

It is important to be aware that highly vulnerable (Tier 1 and Tier 2) assets are not necessarily in imminent danger of flooding. Nor are lower vulnerability (Tier 4 and Tier 5) assets immune to flooding. The values should be read as indicators of the relative vulnerability compared with other assets in the same district (not between the two districts).

## District 1

Figure 2 provides a graph showing the breakdown of asset types within each vulnerability tier in District 1. Bridges and pipes had the greatest proportions of highly vulnerable Tier 1 and Tier 2 assets although the proportions of most vulnerable assets were fairly comparable across all asset types. Figure 3 shows the same information presented in terms of the number of assets by tier.





Figure 4 provides a map illustrating the spatial distribution of flash flood vulnerabilities in District 1. Vulnerabilities tend to be highest for facilities along MN 61 following the shoreline of Lake Superior from Duluth to the Canadian border. This roadway has limited redundancy and crosses many high velocity streams that flow into the lake.

Figure 2: Vulnerability by Asset Type, District 1

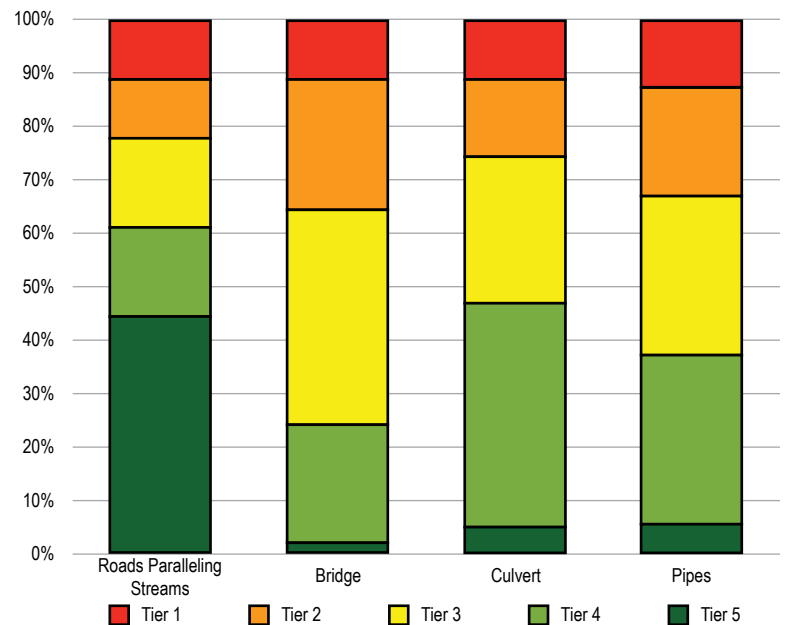


Figure 3: Vulnerability Tiers by Type, District 1

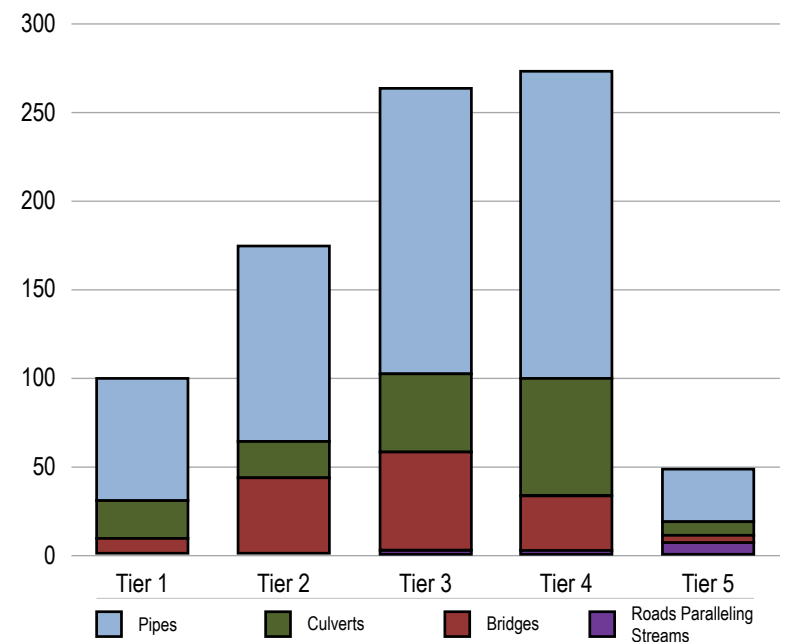
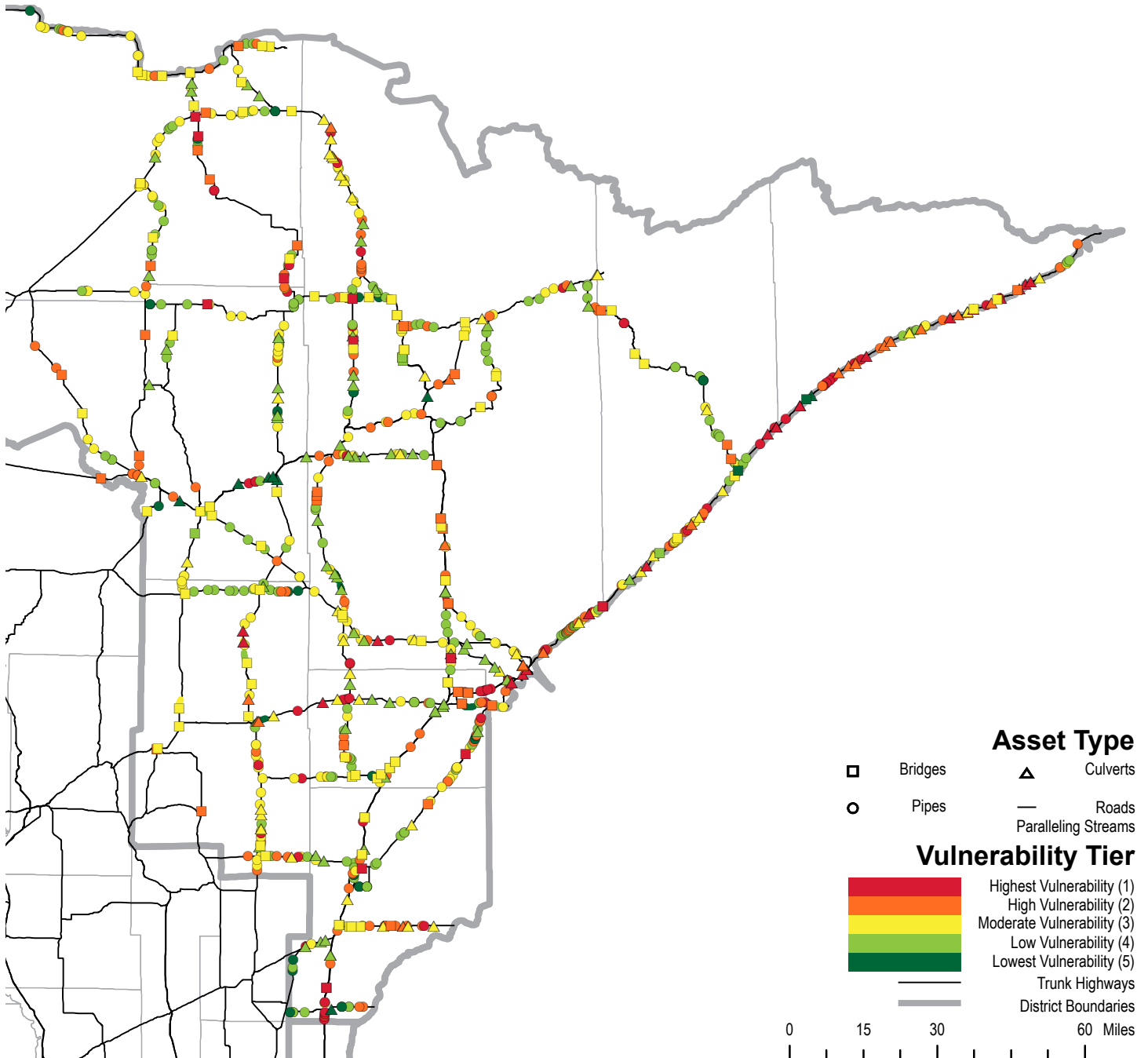


Figure 4

## District 1 Asset Vulnerability Assessment | Weighted by Exposure, Sensitivity & Adaptive Capacity



Highly vulnerable (Tier 1 and Tier 2) assets are not necessarily in imminent danger of flooding, nor are lower vulnerability (Tier 4 and Tier 5) assets immune to flooding. These values are indicators of the relative vulnerability of assets compared with other assets in the same district.



## District 6

Figure 5 provides a graph showing the breakdown of asset types within each vulnerability tier in District 6. High vulnerability (Tier 1 and Tier 2) assets make up a greater proportion of all assets than in District 1. There is greater variation amongst asset types with roads paralleling streams and bridges being much more vulnerable than large culverts and pipes. Figure 6 shows the same information presented in terms of the number of assets by tier.

Figure 7 maps the spatial distribution of flash flood vulnerabilities across District 6. Vulnerabilities tend to be greatest in the hillier eastern portion of the district.

Figure 5: Vulnerability by Asset Type, District 6

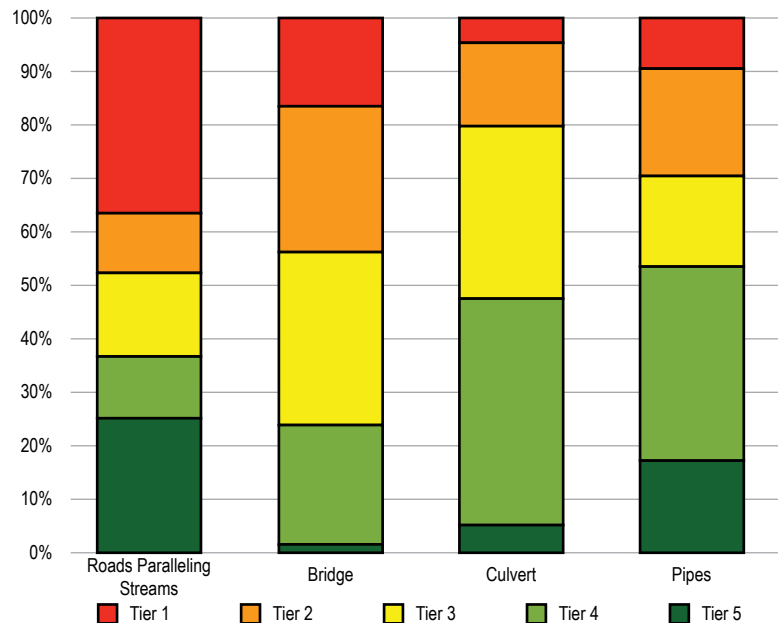


Figure 6: Vulnerability Tiers by Type, District 6

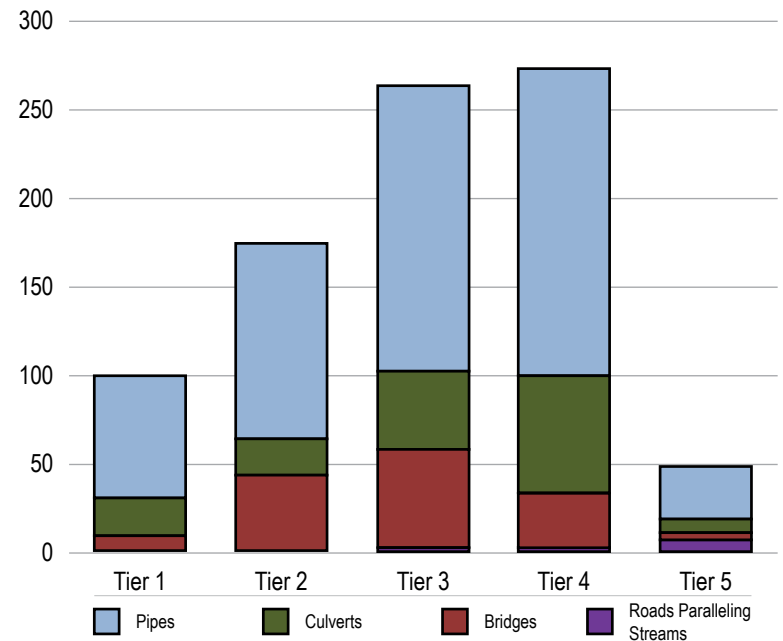
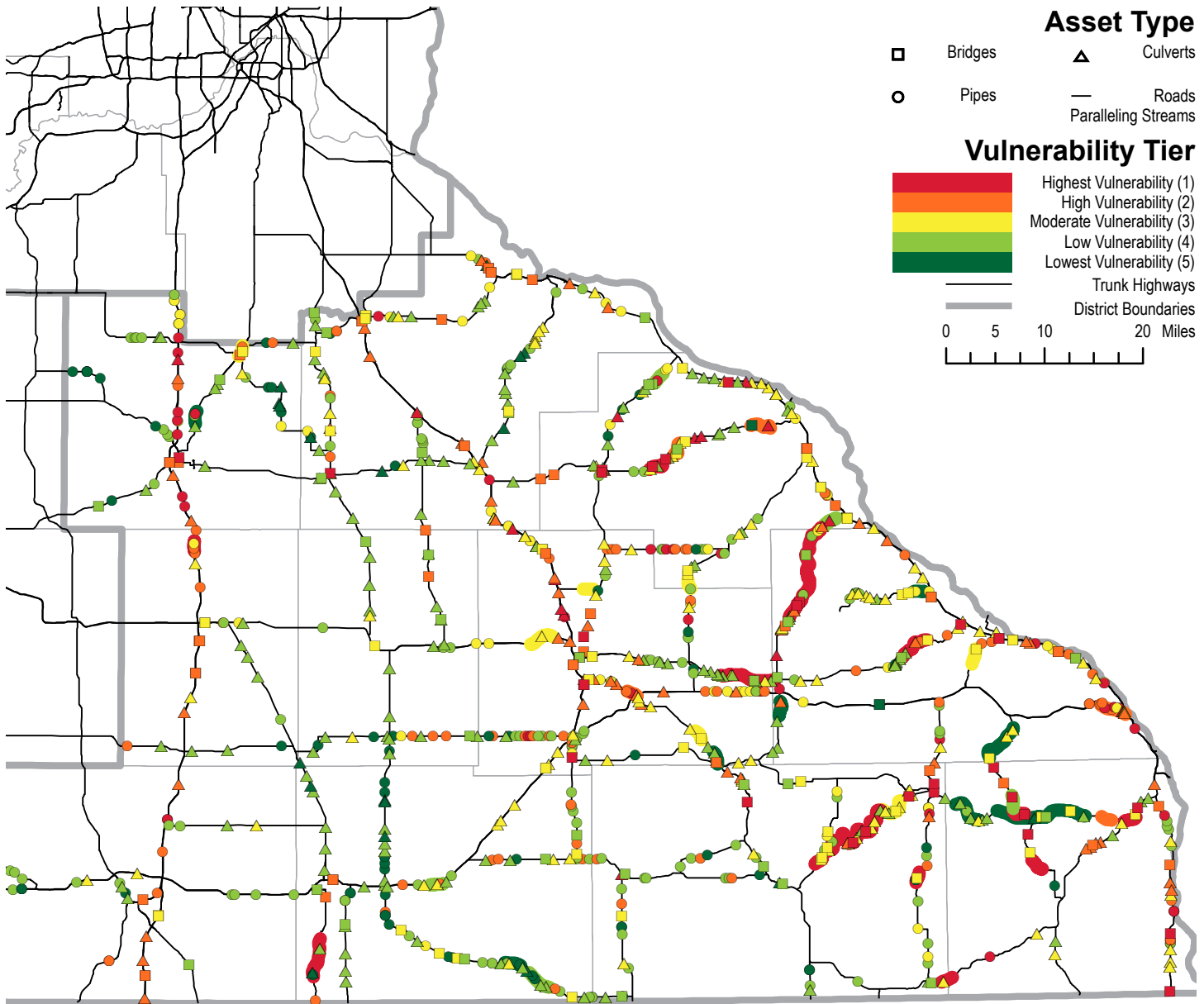




Figure 7

## District 6 Asset Vulnerability Assessment | Weighted by Exposure, Sensitivity & Adaptive Capacity



Highly vulnerable (Tier 1 and Tier 2) assets are not necessarily in imminent danger of flooding, nor are lower vulnerability (Tier 4 and Tier 5) assets immune to flooding. These values are indicators of the relative vulnerability of assets compared with other assets in the same district.



## Action Items

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MnDOT is considering the following action items based on the system-wide vulnerability assessment in Districts 1 and 6:

### LONG RANGE TRANSPORTATION PLANNING ACTIONS

- Test sensitivity of flood vulnerability assessment scoring to different weighting criteria and exclusion of the adaptive capacity component.
- Conduct follow-up assessments on specific assets to identify whether assessment methods are scoring appropriately for observed conditions and, if not, adjust the input metrics, scaling, and weighting appropriately.
- Complete flood vulnerability assessments in other districts
- Use the study results to illustrate the threat posed by flooding/climate change in the next long-range transportation plan

### OPERATIONS AND MAINTENANCE ACTIONS

- Develop emergency action plans for Tier 1 and selective Tier 2 assets
- Explore partnerships with floodplain managers to develop real-time monitoring and warning systems for Tier 1 and 2 assets

### CAPITAL PLANNING ACTIONS

- Incorporate vulnerability assessment scores into the project prioritization system at the state and district levels
- Consider the vulnerability scores when prioritizing culvert replacements, particularly on the National Highway System
- Incorporate considerations of risk into ongoing culvert and bridge improvement programs

### ASSET MANAGEMENT ACTIONS

- Gather data on waterway opening dimensions and other relevant variables that would be useful to future flood vulnerability assessments
- Incorporate vulnerability assessment scores into asset management databases and the asset management plan
- Update MnDOT's risk registers to reflect the vulnerability assessment

## Facility Adaptation Assessments

Once potentially vulnerable facilities have been identified, the next step is to perform more detailed assessments to understand how those vulnerabilities may evolve as the climate changes, develop adaptation options (if necessary), and test their cost-effectiveness. This study describes a process for undertaking facility level adaptation assessments and illustrates its application through two case studies.

The following facilities were chosen for evaluation:

- District 1: A large culvert (MnDOT number 5648) carrying MN 61 over Silver Creek located in the state's Arrowhead Region northeast of Two Harbors (see Figure 8)
- District 6: A large culvert (MnDOT number 5722) carrying US 63 over Spring Valley Creek in the town of Spring Valley, just south of Rochester (see Figure 9)

Both facilities fell into Tier 1 (highest vulnerability) in the system-wide vulnerability assessment. The chosen cases also offered contrasts between rural (the Silver Creek site) and urban (the Spring Valley site). Further, one facility has improvements programmed (the Silver Creek site) while no improvements are currently scheduled for the other (Spring Valley site).

The three greenhouse gas emissions scenarios used in this study were selected to bound the range of possible future climate conditions. The scenarios pivot off the future emission trajectories, known as representative concentration pathways (RCP), that were used in the United Nations' Intergovernmental Panel on Climate Change's (IPCC) 5th Assessment Report (AR5) on climate science. The specific scenarios included:

- Low emissions scenario: RCP4.5
- Medium emissions scenario: RCP6.0
- High emissions scenario: RCP8.5

An even lower emissions scenario, RCP2.6, was considered for the analysis but the project's Climate Advisory Committee felt this scenario was highly optimistic and therefore unlikely to actually occur. Figure 10 provides a graph showing the assumed radiative forcing levels throughout the remainder of this century under the three RCPs used on this project and RCP2.6. The higher the radiative forcing values, the more warming occurs.

Figure 8



Figure 9



Figure 10

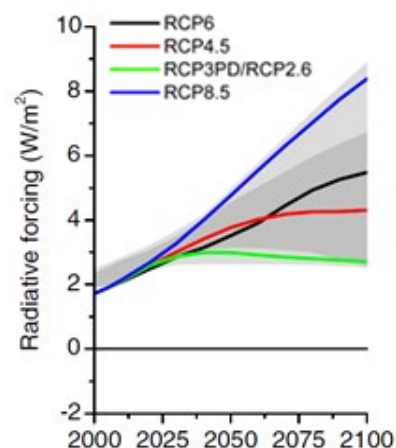


Figure 11: Location of Culvert 5648



## District 1

Culvert 5648 carries MN 61 over Silver Creek and is located northeast of Two Harbors immediately adjacent to Lake Superior. MN 61 is an important link in the National Highway System that runs from Duluth to the Canadian border. The road is also a critical link to tourist destinations along Lake Superior and in the Superior Uplands and Boundary Waters regions. Average annual daily traffic (AADT) at the facility is currently 5,900 vehicles per day and heavy commercial average daily traffic (HCADT) is currently 500 trucks per day. Figure 11 shows the location of the culvert.

Culvert 5648 meets the MnDOT allowable headwater depth design criteria for passing the 50-year storm without overtopping; however, the existing culvert design does not comply with fish passage requirements. In addition, velocities at the culvert exit are much higher than the velocities in the natural channel creating a scour pool at the culvert exit. Due to these deficiencies, it was decided that the existing culvert would most likely not be replaced-in-kind even if climate change were not considered. Table 2 shows an overview of replacement options.

## ADAPTATION OPTIONS

### Option One

Option One is optimized to meet design criteria for the low climate scenario in 2100. It involves replacing the existing culvert with a two-cell 16 foot span (width) by 14 foot rise (height) culvert. This assumes the culvert will be sunk into the stream bed two feet; thus, the water opening height will be 12 feet.

The estimated project cost is \$770,000.



Option Two

Option Two is optimized to meet design criteria for the medium climate scenario in 2100. Discussions with District 1 staff revealed that there is pressure to convert culverts along MN 61 to bridges to further improve fish passage beyond what a culvert can provide. Thus, this option includes the replacement of the existing culvert with a 52 foot simple span bridge. The bridge would have abutments with a one percent slope on both sides. The roadway alignment was assumed to remain the same as the current culvert. Due to the length of the bridge span, the deck depth is three feet. The design follows MnDOT bridge design criteria for crossings of non-navigable waterways.

The estimated project cost is \$1,130,000.

Option Three

Option Three is optimized for the high climate scenario in 2100. In keeping with the emerging practice of replacing culverts with bridges to satisfy fish passage requirements, it satisfies fish passage requirements by including a 57 foot simple span bridge. Similar to Option Two, the bridge would have abutments with a one percent slope on both sides and the roadway alignment is assumed to be the same as the existing facility. Due to the length of the bridge span, the deck depth is 3.4 feet.

The estimated project cost is \$1,210,000.

Table 2: Culvert 5648 Alternatives Overview

Alternative	Optimized For	Project Cost	Worst Case Repair Cost
1	Low Scenario	\$770,000	\$400,000
2	Medium Scenario	\$1,130,000	\$370,000
3	High Scenario	\$1,210,000	\$380,000

A view upstream from Culvert 5648



A view downstream from Culvert 5648



## COST-EFFECTIVENESS ANALYSIS

The project team used a software tool called COAST to assess the cost effectiveness of the climate change adaptation actions. Damage costs accounted for in the model include: physical damage repair costs, incremental travel time costs to motorists from detours, and the potential for injury to motorists.

Key findings of the analysis of potential flooding events include:

- If social costs of detours and injuries are included, Option 1, the expanded two cell culvert, is the most cost effective design in all rainfall increase scenarios (low, medium, and high). See Figure 12 for a graphical comparison.
- If the social costs of detours and injuries are not included, replacement-in-kind of the exiting culvert (with modifications for fish passage) is the lowest cost option if the low rainfall scenario were to occur. If the medium and higher scenarios of rainfall increase were to occur, Option 1 is the most cost effective option. See Figure 13 for a graphical comparison.

Conclusions depend on whether one considers social costs. It is recommended that social costs be included in the analysis, with Option 1 being preferred. Decision-makers should consider other social or political criteria not included in the modeling before deciding on a course of action.



Figure 12: Cost Effectiveness of Culvert 5648 Adaptation Options With Social Costs

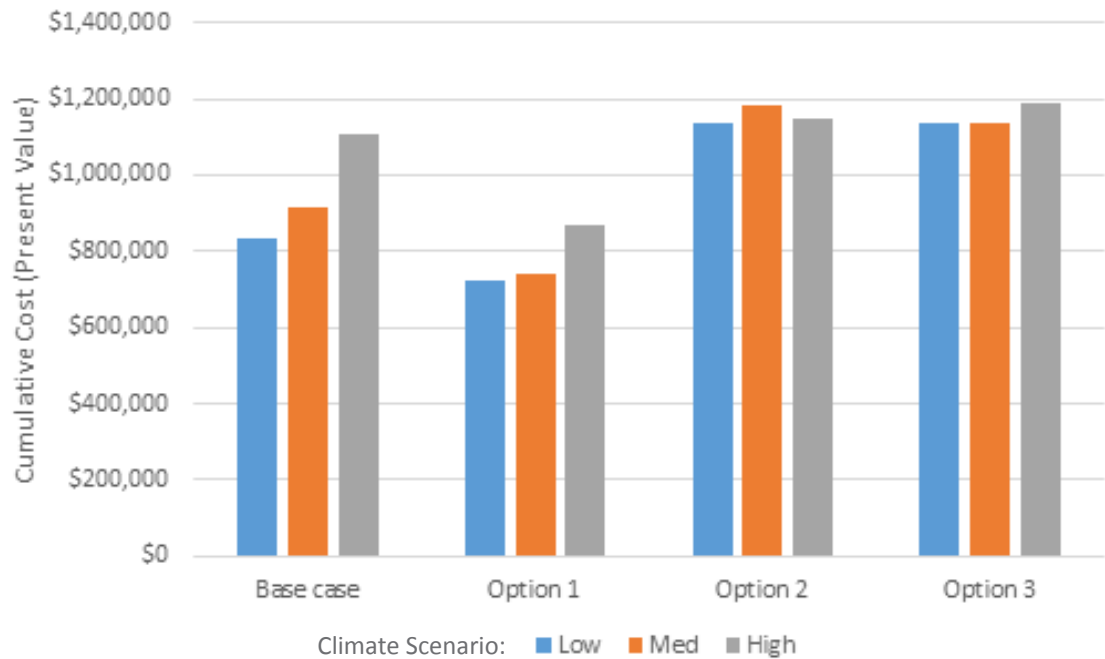


Figure 13: Cost Effectiveness of Culvert 5648 Adaptation Options Without Social Costs

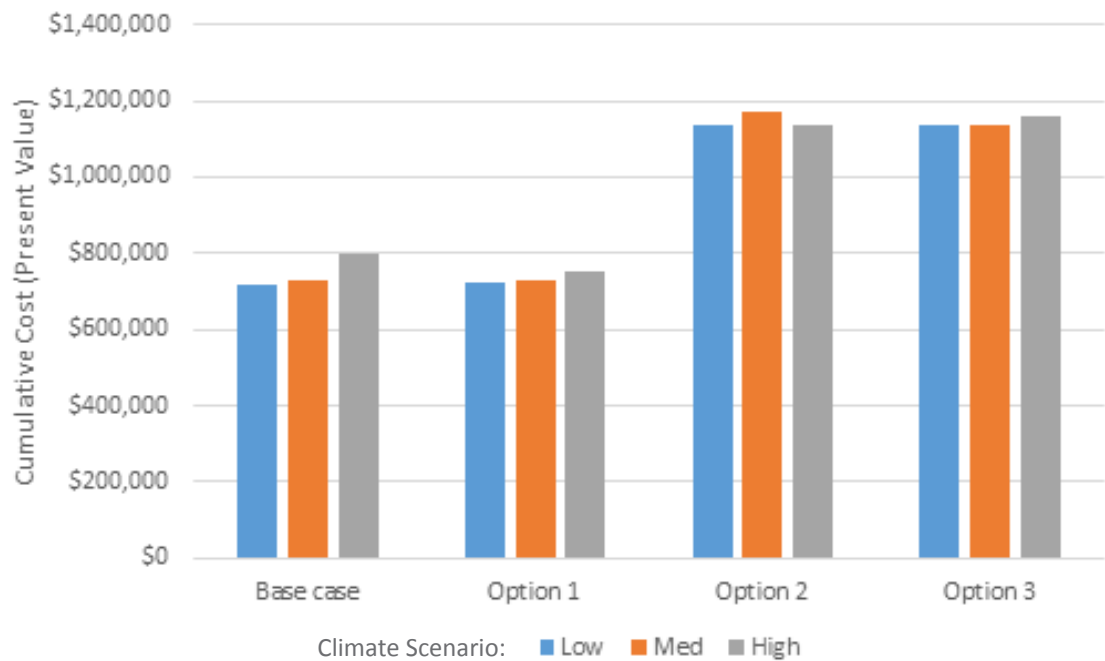


Figure 14: Location of Culvert 5722



## District 6

Culvert 5722 carries US 63 over Spring Valley Creek and is located in the southeast portion of the state in the small town of Spring Valley (see Figure 14). US 63 is an important regional roadway linking the mid-sized cities of Rochester and Waterloo, Iowa and many rural communities in between. AADT at the facility is currently 5,700 vehicles per day and HCADT is currently 610 trucks per day.

The existing facility was analyzed as the base case in this study since no improvements are currently scheduled for the asset. Even under current climate conditions, the culvert is overtopped by storms much weaker than the 50-year design storm.

## ADAPTATION OPTIONS

### Option One

Option One adds two additional 12 foot span (width) by six foot rise (height) cells to the existing culvert design.

The estimated project cost is \$690,000.

### Option Two

Option Two includes the same structural changes as in Option One, but adds a floodplain enhancement upstream of the culvert to give the river room to spread out. This has the effect of lowering peak flow elevations. The work as estimated includes all the items mentioned above for Option One and the additional costs of the floodplain enhancements (including property acquisition and the demolition of one structure).

The total estimated project cost is \$1,640,000.



### Option Three

Option three replaces the existing culvert with a three span bridge with each span being 28 feet in length. This option was designed to meet MnDOT design criteria for the 50-year storm in 2100. The bridge would have abutments with a one percent slope on both sides and two piers. The lowest deck elevation is 1,275.1 feet and the highest point is 1,276.8 feet. In total, the roadway will need to be raised approximately five feet either side of the bridge. The raising of the roadway will necessitate the closing and/or re-design of some intersections with local streets.

The estimated project cost is \$4,210,000.

### COST-EFFECTIVENESS ANALYSIS

The project team used the same software tool and factors as were used in the previous case study. Each alternative's cost effectiveness is compared in Figure 15 (with social costs considered) and Figure 16 (without social costs considered). Detour costs in this analysis were much lower due to a substantially shorter detour route.

The key conclusion of the analysis is that whether or not social costs of detours and injuries are included, Option 1, the expanded five cell culvert, is the most cost effective design in all rainfall increase scenarios (low, medium, and high). Thus, Option 1 would be the preferred option under the range of climate scenarios tested. Decision-makers should consider other social or political criteria not included in the modeling before deciding on a course of action. Additional conditions such as upstream flooding of private property, TMDL credit needs, and the project permitting requirements will need to be fully considered before a final course of action can be selected.

Table 3: Culvert 5722 Alternatives Overview

Alternative	Optimized For	Project Cost	Worst Case Repair Cost
1	Low Scenario	\$690,000	\$300,000
2	Medium Scenario	\$1,640,000	\$410,000
3	High Scenario	\$4,210,000	\$1,560,000

A view upstream from Culvert 5722



A view downstream from Culvert 5722



Figure 15: Cost Effectiveness of Culvert 5722 Adaptation Options With Social Costs

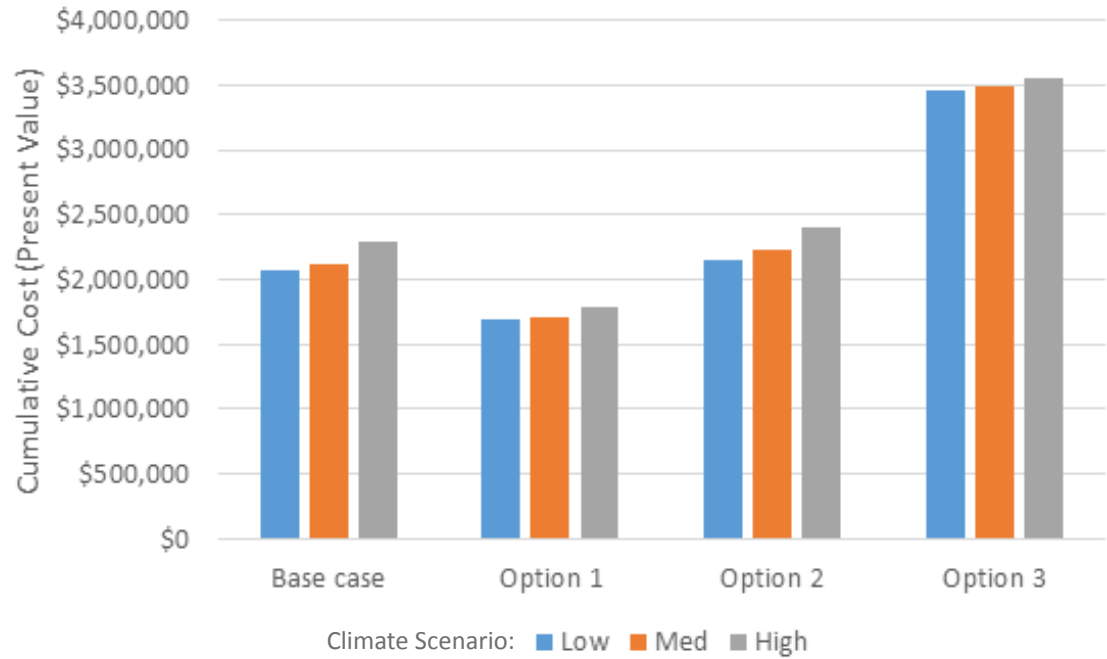
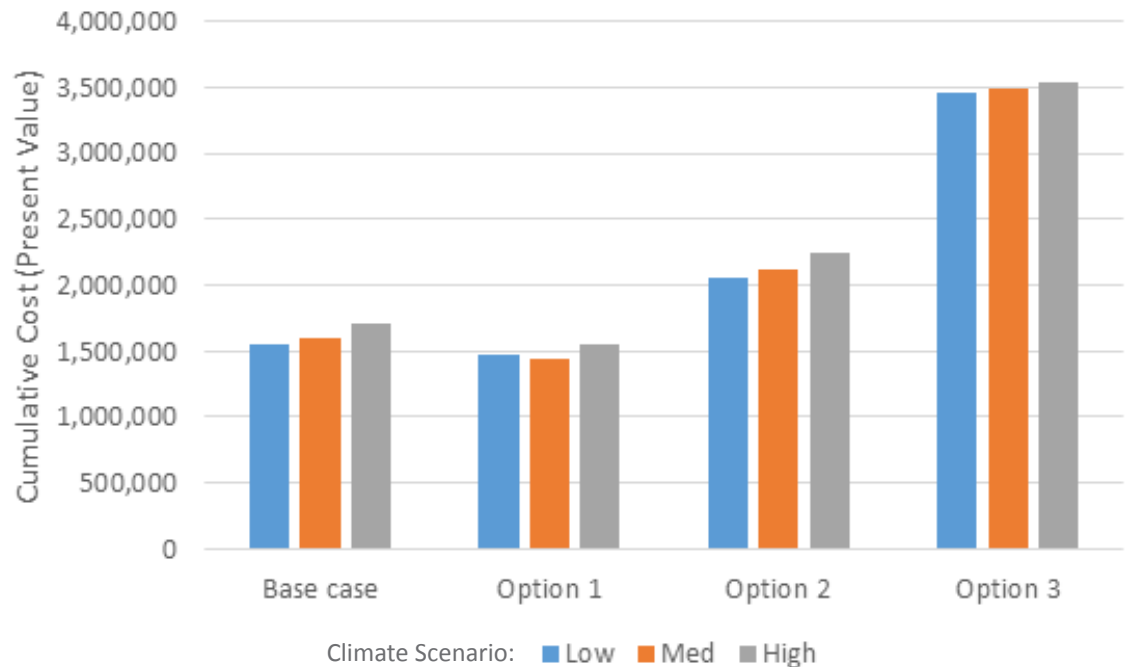


Figure 16: Cost Effectiveness of Culvert 5722 Adaptation Options Without Social Costs



## Action Items

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Given the case study process, MnDOT is considering the following action items with respect to adaptation assessments for individual transportation facilities:

- Project Planning and Design
  - Consider conducting facility-level adaptation assessments on assets from the system-wide vulnerability analysis that are under-capacity (not capable of passing the 50-year design storm), have high social costs of failure (high traffic volumes or long detour routes), and are not planned for replacement.
  - Consider conducting the facility-level adaptation assessment process on all major projects with potential exposure to climate change.
  - Use facility-level adaptation assessment process to justify betterments through ER funding after flooding damage occurs.
- Capital Planning
  - Incorporate cost-effective proactive adaptation projects from facility-level assessments into the capital plan.
- Research
  - Monitor updates to climate projections and advances in climate downscaling methodologies.

## Additional Information

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More information about the project and detailed reports can be found at [www.mndot.gov/climate](http://www.mndot.gov/climate)