JULY 2024

Resilience Improvement Plan

Prepared for:

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1.0 Background

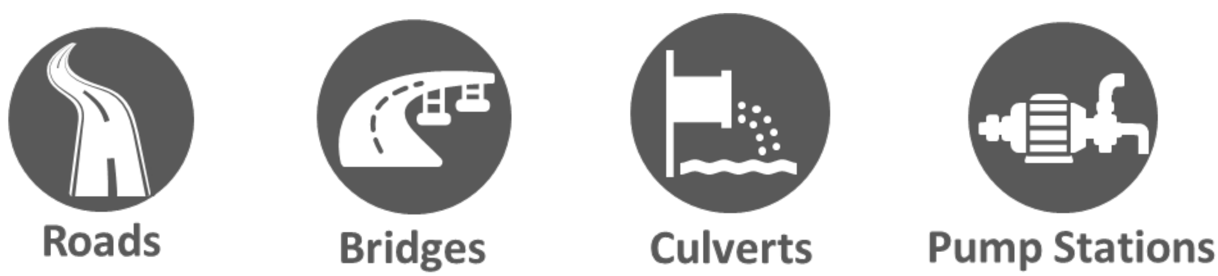
1.1 Introduction and Purpose

The Michigan Department of Transportation (MDOT), in collaboration with statewide and regional stakeholders, developed this Resilience Improvement Plan. The purpose of the plan is to explore strategies to improve statewide transportation resilience to climate hazards. Input from stakeholders across the state was crucial to developing a plan that considers Michigan's diverse communities and identifies resilience strategies that are implementable across the state.

The plan was informed by the Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) Program which was established through the Bipartisan Infrastructure Law passed in 2021. The plan considered climate hazards that impact Michigan including flooding, extreme heat, and coastal erosion. Climate hazards are natural events that can cause damage or loss to the human-built and natural environment, including to transportation infrastructure. Resilience improves the ability of transportation assets to withstand changing climate conditions, thereby reducing the vulnerability of transportation assets to climate impacts. Resilient transportation systems maintain safe and effective transportation throughout Michigan and ensure continued access to homes, businesses, essential services, and community facilities.

The purpose of this Resilience Improvement Plan is to evaluate vulnerabilities, assess the risk associated with climate hazards, and identify strategies to improve the resilience of surface transportation facilities to climate hazards in Michigan. This plan focuses on four key transportation assets including roads, bridges, culverts, and pump stations (**Figure 1**).

Figure 1. Assets Studied in this Resilience Improvement Plan



1.2 Overview of Legislation

1.2.1 Bipartisan Infrastructure Law

The Bipartisan Infrastructure Law, also known as the Infrastructure Investment and Jobs Act, was passed in 2021 and established the PROTECT Grant Program (23 U.S.C. § 176).[i] The PROTECT Program provides funding to address climate change by improving surface transportation resilience to climate hazards, such as flooding, coastal erosion, and extreme heat. Program funds for resilience improvements can be used for highways, public transportation, ports, and intercity passenger rail and should support the continued operation or rapid recovery of surface transportation facilities. Further, projects should use collaborative approaches to risk reduction, including the use of natural infrastructure.

The Bipartisan Infrastructure Law encourages states to develop resilience improvement plans through the PROTECT Program. Through resilience improvement plans, the PROTECT Program aims to identify and fund projects that will protect (23 U.S.C. § 176):

- "Surface transportation assets by making them more resilient to current and future weather events and natural disasters, such as severe storms, flooding, drought, levee and dam failures, wildfire, rockslides, mudslides, sea level rise, extreme weather, including extreme temperature, and earthquakes;
- Communities through resilience improvements and strategies that allow for the continued operation or rapid recovery of surface transportation systems that serve critical local, regional, and national needs, including evacuation routes, and that provide access or service to hospitals and other medical or emergency service facilities, major employers, critical manufacturing centers, ports and intermodal facilities, utilities, and Federal facilities;
- Coastal infrastructure, such as a tide gate to protect highways, that is at long-term risk to sea level rise;
- Natural infrastructure that protects and enhances surface transportation assets while improving ecosystem conditions, including culverts that ensure adequate flows in rivers and estuarine systems." [ii]

This Resilience Improvement Plan identifies the assets most at-risk to climate hazards and helps prioritize those risks for future funding, project development, and implementation.

1.2.2 Justice40 Initiative

The Justice40 Initiative was signed in 2021 under Executive Order 14008. According to Section 223, eligible agencies, such as MDOT, must work toward the goal of having 40 percent of the overall benefits of federal investments flow to disadvantaged communities. The U.S. Department of Transportation defines disadvantaged communities based on six impact categories: transportation, health, environment, economy, resilience, and equity. Resilience improvement strategies, and associated projects, should benefit disadvantaged communities in alignment with the Justice40 Initiative.

1.2.3 Alignment with Other State Plans

This Resilience Improvement Plan was developed in alignment with the state goals outlined in the Michigan Mobility 2045 Plan (MM2045), the state's long-range transportation plan, the July 2022 Transportation Asset Management Plan (TAMP), and other studies and reports conducted within the state.[iii] [iv]

This Resilience Improvement Plan was developed to support the following vision from the MM2045 Plan:

"In 2045, Michigan's mobility network is safe, efficient, future-driven, and adaptable. This interconnected multimodal system is people-focused, equitable, reliable, and convenient for all users, and enriches Michigan's economic and societal vitality. Through collaboration and innovation, Michigan will deliver a well-maintained and sustainably funded network where strategic investments are made in mobility options that improve quality of life, support public health, and promote resiliency."

Additionally, the TAMP cites the need to integrate resilience into its planning procedures and processes, as well as the need to perform a new assessment of climate impacts. The TAMP also identified climate impacts as "Program Threats Most Hazardous to MDOT."

In 2015, MDOT released the *Michigan DOT Climate Vulnerability Assessment Pilot Project Final Report* as part of the Federal Highway Administration's climate change vulnerability assessment program.[v] The study followed *FHWA's Climate Change and Extreme Weather Vulnerability Assessment Framework* and identified Michigan's primary climate hazards, assessed risks, and defined strategies to incorporate the results into Michigan's decision-making. The study focused on precipitation and extreme heat.[vi]

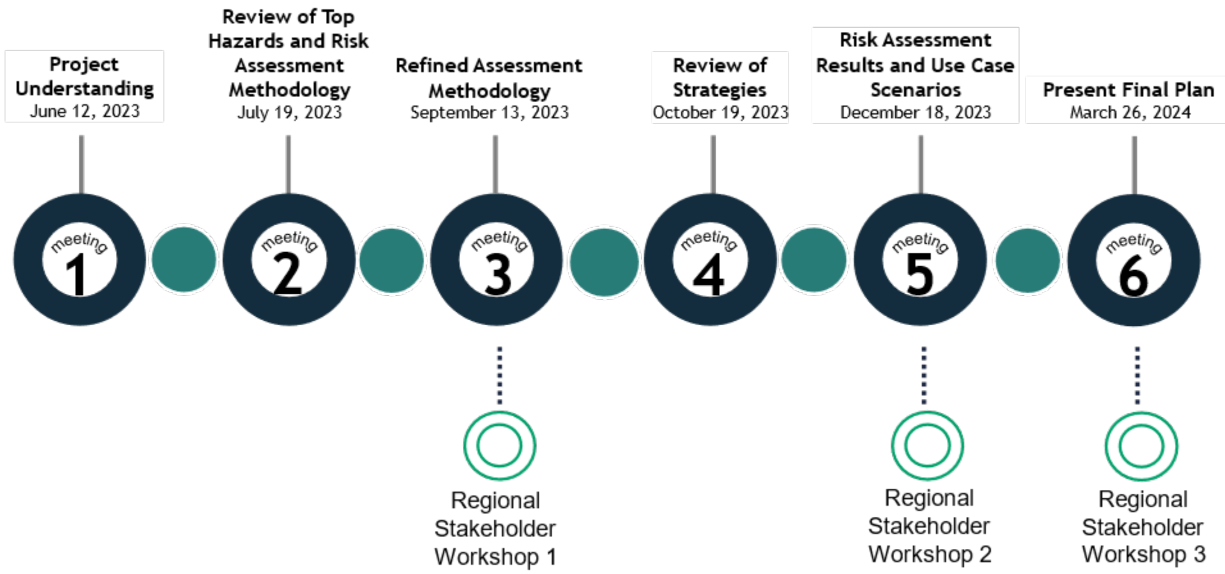
In 2020, the Southeast Michigan Council of Governments (SEMCOG) *Climate Resiliency and Flood Mitigation Study* assessed flooding risk for roads, culverts, pump stations, and bridges for the SEMCOG region. The study identified key indicators for flood exposure, sensitivity, and criticality for each asset type.

This Resilience Improvement Plan used the methodology from the SEMCOG study and information from the 2015 Pilot Project as a launching point for the development of the risk assessment (Section 3.0), with adjustments to include additional hazards, a larger geographic area, and more emphasis on reducing risk associated with climate hazards for disadvantaged communities.

1.3 Stakeholder and Agency Involvement

MDOT worked with stakeholders from across the state to inform the development of this Resilience Improvement Plan. Input from stakeholders was crucial to developing a plan that considers Michigan's climate hazards, existing resilience efforts, and identifies implementable strategies. MDOT collaborated with stakeholders through two groups: the Internal Advisory Committee and the Regional Stakeholder Workshop Group. The Internal Advisory Committee included representatives across MDOT, State of Michigan agencies, and the Federal Highway Administration. The Regional Stakeholder Working Group consisted of larger groups of representatives across the state, including metropolitan planning organizations, regional planning commissions, transportation agencies, and councils of government, among others. Input gathered from stakeholders was incorporated into this Resilience Improvement Plan after each meeting to consider Michigan's diverse needs. The final meeting presented this Resilience Improvement Plan and focused conversations on the potential use case scenarios and a path forward for implementation. This meeting provided an opportunity for the Regional Stakeholder Working Group to provide their input on the use case scenario locations, proposed strategies for resilience, and considerations for implementation that coordinate resilience efforts across the state. **Figure 2** presents the stakeholder milestones.

Figure 2. Stakeholder Engagement Timeline



2.0 The Changing Climate in Michigan

Multiple climate hazards occur within Michigan, including flooding, tornadoes, ice storms, extreme heat, drought, wildfires, and coastal erosion. Michigan has been an active partner in addressing climate hazards through the development of hazard mitigation plans, emergency response procedures, and this Resilience Improvement Plan.

Climate change is increasing the frequency and magnitude of climate hazards in Michigan. According to the Fifth National Climate Assessment, the United States has been warming since the 1970s, leading to declining extreme cold weather events and increasing frequency, intensity, and duration of extreme heat.[vii] Annual precipitation increased across much of the Midwest from 1992 to 2021, and future projections suggest this trend will continue.[viii] Changes in temperature and precipitation patterns also influence whether water falls as rain or snow, as well as the accumulation of ice and timing of snow melt. These key factors influence the water levels and ice cover of the Great Lakes, which influence changes along the Great Lakes coastlines (e.g., erosion).

This Resilience Improvement Plan focused on the top climate hazards—flooding (riverine, coastal, and stormwater), extreme heat, and coastal erosion—impacting Michigan (**Figure 3**).

Figure 3. Climate Hazards Analyzed in this Resilience Improvement Plan

2.1 Flooding

Flooding is not uncommon in Michigan and the risk of flooding is increasing with climate change. Michigan experiences both stormwater flooding and flooding from riverine and coastal sources. Heavy rains can overwhelm stormwater systems and increase water elevations in lakes, rivers, and streams, resulting in flooding. The stress of water on transportation assets can cause structural damage, require road closures during and after a flood event, and weaken or wash out the soil that support roads and bridges (**Figure 4**).[ix] In 2019, it was estimated that statewide expected losses from flooding were more than $100 million, nearly four times higher than what was estimated in 2014.[x] The frequency and intensity of heavy rain events in Michigan is projected to increase, which could result in more frequent and intense flooding.[xi] In particular, heavy rain events are projected to increase in the spring and winter.[viii]

2.1.1 Stormwater Flooding

Stormwater flooding occurs when rainfall rates are higher than the capacity of the stormwater system and/or when the stormwater system is not functioning as designed.[xii] Michigan has an $800 million annual gap in water and sewer infrastructure needs.[xiii] Much of Michigan's infrastructure is aging and was built based on now outdated design standards. In 2014, a 500-year flood event incurred $1.8 billion in damages to the City of Detroit.[xiv] According to the MM2045 Plan, in 2021, parts of Detroit experienced major flooding when 6 inches of rain overwhelmed stormwater infrastructure and flooded several sections of major freeways that are depressed, including portions of I-94, I-96, and I-75.[xv] As climate change increases both rainfall intensity and duration, infrastructure needs will grow and stormwater flooding will worsen, which will negatively impact residents and the community.[xvi]

2.1.2 Riverine and Coastal Flooding

Riverine flooding occurs when a river overflows its banks and floods the surrounding areas.[xvii] While much of Michigan has a relatively low riverine flooding risk, large riverine flood events can still occur.[xviii] In 2013, historic flooding along the Grand Rapids River affected many homes and businesses, resulting in road closures and detours until floodwater receded.[xix] In 2018, nearly 7 inches of rain fell in Houghton County, which caused Sturgeon River and Trap Rock River to overflow their banks and resulted in widespread damages, including along US-41 and M-26.[xx] In 2020, heavy rainfall occurred in Midland County, Michigan. This heavy rainfall led to the collapse of two dams, leading to major flooding in the area and the federal government declaring it a major disaster.[xxi] [xxii] Flooding is likely to increase in Michigan as average annual precipitation increases and the severity of storms intensifies.[xxiii]

Figure 4. Roadway Flooding in Midland County, Michigan

Coastal flooding in Michigan is a result of both prolonged higher water levels since 2019 and the result of shorter-term extreme weather.[xxiv] Approximately 300 miles of Michigan's Great Lakes coastline is subject to coastal flooding. In 2020, the Michigan Municipal League collected data on recent (approximately 2018 to 2020) coastal flooding damages from 32 coastal communities. The total cost was estimated at more than $68 million.[xxv]

The Federal Emergency Management Agency (FEMA) flood mapping captures both coastal and riverine flood hazards within the Flood Insurance Rate Maps (FIRMs). Therefore, for the purposes of this risk assessment, both coastal and riverine flooding were assessed together.

2.2 Coastal Erosion

Coastal erosion is a geological process describing the washing away of soils and material from a shoreline, thereby reducing the amount of land between built structures, such as roadways, and bodies of water, such as the Great Lakes. Coastal erosion destabilizes infrastructure by removing the subsurface soils and material on which the infrastructure is supported. Over time, the removal of subsurface soils can create cracks and breaks in infrastructure or result in the loss of infrastructure into water bodies. Michigan has more than 3,288 miles of Great Lakes shoreline.[xxvi] Approximately 250 miles of shoreline in Michigan are classified as high-risk erosion areas.[xxvii] High-risk erosion areas are areas eroding at an average rate of 1 foot or greater per year over at least 15 years; however, some erosion rates along the shoreline may be as high as 17 feet per year.[xxviii] In 2019, coastal erosion caused damage to 3 miles of roadway along M-185, posing safety concerns.

» *erosion rates* may be *as high as 17 feet per year*

2.3 Extreme Heat

Extreme heat is a top priority hazard in Michigan, based on the potential for widespread human impacts and the burden on infrastructure.[xxix] **Figure 5** depicts how the temperature of transportation assets can exceed the temperature of the air, depending on the material used.[xxx] Extreme heat places stress on transportation assets and can result in buckling, softening asphalt, and rutting, which leads to cracking and potholing. Such deterioration has safety impacts for users of the roadway and increases maintenance costs. Extreme heat also poses health threats for pedestrians, cyclists, and public transportation users, especially in urban centers. In 2018, extreme heat led to seven instances of highways buckling, resulting in safety concerns and road closures.[xxxi] Average annual temperatures have been increasing over the last several decades, a trend that is projected to continue.[xxxii]
By midcentury (2040 through 2059), it is estimated that there will be an average of 13 additional days per year that reach temperatures above 90 degrees Fahrenheit (°F).[xxxiii]

Figure 5. Impact of Heat on Concrete and Asphalt

AIR TEMPERATURE	CONCRETE TEMPERATURE	ASPHALT TEMPERATURE
85°F	105°F	130°F
91°F	125°F	140°F
97°F	145°F	150°F

3.0 Risk Assessment

3.1 Methodology

The risk assessment conducted as part of this Resilience Improvement Plan identified risk scores for roadways, bridges, culverts, and pump stations located within the state of Michigan. Based on a review of the literature and stakeholder engagement, the risk assessment focused on four of Michigan's top hazards: riverine/coastal flooding, stormwater flooding, heat, and coastal erosion. The assessment drew on several previously completed studies in the development of the methodology, most prominently from the 2020 SEMCOG *Climate Resiliency and Flooding Mitigation Study Report*.[xxxiv] The SEMCOG methodology used a series of exposure, sensitivity, and criticality indicators to assess flood risk for roadways, bridges, culverts, and pump stations within the SEMCOG region. The methodology for this risk assessment used the same risk equation and many of the same indicators for flood exposure, sensitivity, and criticality as the SEMCOG *Climate Resiliency and Flooding Mitigation Study Report*. This assessment also applied the same or similar weights to these indicators (Appendix A provides additional information on weights). To align with the *PROTECT Formula Program Implementation Guidance* as part of the Bipartisan Infrastructure Law, the methodology for this risk assessment was updated to include multiple hazards beyond flooding and incorporate social vulnerability data, and it was expanded to a statewide assessment. The following sections discuss the key definitions, the hazards assessed, and the approach. **Figure 6** depicts the assets analyzed in this plan. Bridges, culverts, and pump stations were assessed as individual assets. Roadways were assessed based on roadway segments (i.e., a portion of road between two intersections).

Figure 6. Transportation Assets Analyzed for Climate Hazard Risk

149,839 Miles of Roads

11,300 Bridges

48,971 Culvert Locations

157 Pump Stations

3.1.1 Key Definitions

Assessing the risk of a particular asset to a climate hazard is a multistep analysis that incorporates numerous factors. Risk is a function of the vulnerability and criticality of an asset. Risk identifies the likelihood of an event occurring and the consequences of that event. Vulnerability is a function of the exposure and sensitivity of an asset has to a particular climate hazard. **Figure 7** depicts the key definitions for understanding risk which have been adjusted from the SEMCOG *Climate Resiliency and Flooding Mitigation Study*.[xxxv]

Figure 7. Key Definitions for Understanding Risk

3.1.2 Climate Hazards Evaluated

This plan identified four climate hazards to evaluate vulnerability, assess risk, and identify initiatives to improve the resilience of the transportation system: (1) riverine/coastal flooding, (2) stormwater flooding, (3) coastal erosion, and (4) extreme heat. These hazards were identified based on the history of previous disaster occurrences in the state, a review of existing literature, and stakeholder input.

MDOT analyzed the risk associated with riverine/coastal flooding, stormwater flooding, coastal erosion, and extreme heat on transportation assets across the state and identified initiatives to improve the capacity of the transportation system to withstand and recover from climate hazard events. Improving the resilience of the transportation system to climate hazards maintains safe and effective transportation throughout Michigan.

To incorporate climate change projections and align with the SEMCOG *Climate Resiliency and Flooding Mitigation Study Report*, the risk assessment used downscaled climate modeling data from the University of Wisconsin–Madison's Center for Climatic Research. The SEMCOG *Climate Resiliency and Flooding Mitigation Study Report* used the Center for Climatic Research's projected change in days with precipitation greater than 3 inches as a flooding indicator. As described in the following section, this risk assessment used the same data as a flooding indicator and incorporated temperature projections from the same source as a heat indicator.

3.1.3 Approach

The risk assessment used a series of indicators to assess the exposure, sensitivity, and criticality to calculate risk for each asset type. To assess risk to flooding, indicators were based on the 2020 SEMCOG *Climate Resiliency and Flooding Mitigation Study* and modified to align with statewide data availability and meet the needs of this Resilience Improvement Plan. For example, some flooding indicators were removed if statewide data were not available or if statewide analysis was not feasible. Additionally, culvert sensitivity indicators were removed because MDOT is in the process of updating culvert data, and only culvert location, size, and material were available statewide at the time of this assessment. To better identify applicable resilience strategies to reduce flood risk, this assessment also separated riverine and coastal flood risk from stormwater flood risk. For coastal erosion and heat risk, indicators were determined based on best practices, professional judgment, and data availability. The overall risk equation used in this assessment was based on the risk equation used in the SEMCOG study, with the exception of culvert risk from all hazards and coastal erosion risk to all assets, which did not include sensitivity indicators in the risk equation. Following are additional details on the approach.

3.1.3.1 Exposure

As described in Section 3.1.1, exposure is the extent to which an asset experiences the direct effects of a hazard. Exposure indicators vary by both hazard type and asset type. Following are descriptions and assumptions for the exposure indicators.

- Flooding – Riverine/Coastal:
  - Past flooding experience: Assets within 100 feet of a location identified as having experienced flooding issues in the past were considered more likely to flood again and rated a higher score for the past flooding experience indicator. Past flooding experience data were based on MDOT records from 2015 through 2022 and stakeholder input. The data were further categorized as either riverine/coastal or stormwater based on proximity to a riverine/coastal flood source and professional judgment.
  - FEMA flood zone: Assets located within or near a FEMA floodplain were considered more likely to be exposed to future riverine/coastal flood hazards. Assets were scored highest if they were located within the 100-year floodplain. Michigan does not have digital FEMA maps for all counties in the state. In areas where no digital FEMA maps are available, assets received a score of 1 (low exposure) for the FEMA flood zone indicator.
  - Projected change in days with precipitation greater than 3 inches (days/decade): Downscaled climate projection data were used to map precipitation projections by the mid-21st century across Michigan.[xxxvi] Assets located in the areas of Michigan projected to experience the greatest change in precipitation were considered more exposed.
- Flooding – Stormwater:
  - Past flooding experience: Assets within 100 feet of a location identified as having experienced flooding issues in the past were considered to be more likely to flood again and were given a higher score for the Past Flooding Experience indicator. Past flooding experience data were based on MDOT records from 2015 through 2022. The data were then categorized as either riverine/coastal or stormwater based on proximity to a riverine/coastal flood source and professional judgment. To assess stormwater flood risk to roadways, the top 200 highest risk roadway segments were manually reviewed to ensure stormwater impacts were assigned to the correct roadway at intersecting roads.

  - Impervious surface: Percent impervious surface was calculated for each watershed (hydrologic unit code 14) within Michigan. Watersheds with high percentages of impervious surface were considered more likely to be exposed to stormwater flooding because of the faster runoff rates and less infiltration.
  - Projected change in days with precipitation greater than 3 inches (days/decade): Downscaled climate projection data were used to map precipitation projections by the mid-21st century across Michigan.[xxxvii] Assets located in the areas of Michigan projected to experience the greatest change in precipitation were considered more exposed.
- Coastal Erosion:
  - Coastal erosion: Michigan's high-risk erosion zones provide 30- and 60-year projected recession rates in feet and were created to help determine setbacks for each zone.[xxxviii] These rates do not account for changes in precipitation resulting from climate change. For the purposes of this risk assessment, assets located within these zones were considered exposed to coastal erosion.
- Heat:
  - Impervious surface: Assets located in watersheds with high percentages of impervious surface were considered more exposed to heat hazards because of the ability of impervious surfaces to retain heat and impact the temperatures of surrounding areas.
  - Projected change in days with temperatures greater than 90°F: Downscaled climate projection data were used to map precipitation projections by the mid-21st century across Michigan. Assets located in the areas of Michigan projected to experience the greatest change in days above 90°F were considered more exposed. Ninety degrees Fahrenheit was selected as the temperature threshold because concrete and asphalt temperatures can be significantly higher than the surrounding air temperatures, as mentioned in Section 2.3.
  - Heat severity: The Trust for Public Land heat severity layer maps areas of cities that are hotter than the average temperature for the given city.[xxxix] The data set is based on temperatures from the summer of 2021. Assets located in areas with greater relative heat severity were considered more exposed.

Table 1 illustrates the exposure indicators used in the risk assessment by asset and hazard.

Table 1. Exposure Indicators by Asset Type and Hazard

Hazard	Roadways	Bridges	Culverts	Pump Stations
Flooding – Riverine/Coastal	▪ Past Flooding Experience ▪ FEMA Flood Zone ▪ Change in Days with Precipitation More Than (>) 3 inches	▪ Past Flooding Experience ▪ FEMA Flood Zone ▪ Change in Days with Precipitation >3 inches	▪ Past Flooding Experience ▪ FEMA Flood Zone ▪ Change in Days with Precipitation >3 inches	▪ Past Flooding Experience ▪ FEMA Flood Zone ▪ Change in Days with Precipitation >3 inches
Flooding – Stormwater	▪ Past Flooding Experience	▪ N/A	▪ Past Flooding Experience	▪ Past Flooding Experience

Hazard	Roadways	Bridges	Culverts	Pump Stations
	▪ Impervious Surface ▪ Change in Days with Precipitation >3 inches		▪ Impervious Surface ▪ Change in Days with Precipitation >3 inches	▪ Impervious Surface ▪ Change in Days with Precipitation >3 inches
Coastal Erosion	▪ High-Risk Erosion Zone	▪ High-Risk Erosion Zone	▪ High-Risk Erosion Zone	▪ High-Risk Erosion Zone
Extreme Heat	▪ Impervious Surface ▪ Change in Days Above 90°F ▪ Heat Severity ▪	▪ Impervious Surface ▪ Change in Days Above 90°F ▪ Heat Severity ▪	▪ N/A ▪	▪ N/A ▪

3.1.3.2 Sensitivity

Sensitivity describes the way in which an asset is impacted when exposed to a hazard. The combination of exposure and sensitivity reflects the overall vulnerability of an asset. Similar to exposure, the sensitivity indicators are specific to the hazard and the asset type. No indicators were used to assess coastal erosion sensitivity. The assessment anticipated that if an asset were located in the High-Risk Erosion Zone, its vulnerability could be reasonably determined by location alone. Additionally, because culvert data were still in the process of being collected at the time of the assessment, no culvert sensitivity indicators were included. Following are descriptions of sensitivity indicators and assumptions.

- Flooding (Riverine/Coastal and Stormwater):
  - Road pavement condition: Roadways with poor or fair conditions were regarded as more sensitive to damage from flooding. Pavement condition was not available for all roadways. If pavement condition was not available, a roadway received a default value of 1 (low sensitivity).
  - Bridge condition: Bridges identified to be in worse condition were judged to be more susceptible to damage from flooding events.
  - Bridge age: Older bridges were considered more susceptible to damage from flooding than newer bridges. Bridge age was based on either the year the structure was built or the year it was reconstructed, if applicable.
  - Bridge scour criticality: Bridges with high values for scour criticality were considered to be more sensitive to flood damage.
  - Pump station condition: Pump stations in poor or fair conditions were considered more sensitive to flood damage than those identified as good or programmed (i.e., pump stations that have been funded for upgrades). Pump station ratings are based on the mechanical, electrical, structural, and site condition.[xl]
  - Pump station age: Pump stations that were 60 years or older were identified as more sensitive to flood damage.

  - Pump station access issues: If a pump station had been identified as experiencing access issues in the past, it was considered more sensitive to flood hazards. These pump stations may be hard to access during future flood events.
- Heat:
  - Roadway pavement condition: Roadways with poor or fair pavement conditions were considered to be more sensitive to extreme temperatures. Pavement condition was not available for all roadways. If pavement condition was not available, a roadway received a default value of 1 (low sensitivity).
  - Roadway pavement material: Various pavement materials are more heat resistant than others. Based on professional engineer assumptions, bituminous, asphalt-concrete (AC) overlay over existing AC pavement, AC overlay over existing jointed concrete pavement, and AC (Bi overlay over existing Continuously Reinforced Concrete Pavement [CRCP]) were considered to be more susceptible to damage from extreme heat.
  - Bridge condition: Bridges identified to be in worse condition were considered to be more susceptible to damage from extreme heat.
  - Bridge age: Older bridges were considered more susceptible to damage from heat than newer bridges. Bridge age was based on either the year the structure was built or the year it was reconstructed, if applicable.

Table 2 illustrates the indicators used to calculate each asset's sensitivity score.

Table 2. Sensitivity Indicators by Asset Type and Hazard

Hazard	Roadway	Bridges	Culverts	Pump Stations
Flooding (Riverine/Coastal & Stormwater)	• Pavement Condition	• Condition • Age • Scour Criticality	• N/A	• Condition • Age • Access Issues
Coastal Erosion	• N/A	• N/A	• N/A	• N/A
Heat	• Pavement Condition • Pavement Material	• Condition • Age	• N/A	• N/A

3.1.3.3 Criticality

Criticality describes the estimated importance of an asset to the transportation system or region. Criticality is independent of exposure and vulnerability. Criticality helps prioritize vulnerable assets. Criticality indicators were determined using the SEMCOG study as a baseline. A major change from the SEMCOG study in the criticality calculation was the inclusion of the Climate and Economic Justice Screening Tool (CEJEST) data to align with the Justice40 Initiative and account for disadvantaged communities in the criticality calculation. Based on stakeholder feedback, the criticality score also incorporated National Highway System data. Unlike exposure and sensitivity indicators, criticality indicators are the same across asset and hazard types. For pump stations and culverts, the criticality indicators are based on the indicators for the nearest road. Following are descriptions and assumptions for criticality indicators.

- Traffic Volume:
  - Assets located on or near roadways with high traffic volume were considered more critical. Traffic volume was based on average annual daily traffic (AADT). The highest 25th percentile was scored as the most critical.
- Truck Traffic Volume:
  - Assets located on or near roadways with high truck traffic volume were considered more critical. Truck traffic volume was based on commercial AADT. The highest 25th percentile was scored as the most critical. Routes with high truck traffic were assumed to be crucial to maintaining the supply chain.
- Functional Classification:
  - Assets located on or near roadways with higher functional classification were considered more crucial to the transportation network.
- National Highway System:
  - Assets located on or near National Highway System roadways were considered to be more critical to the transportation system, supply chain networks, and military routes.
- CEJEST Disadvantaged Communities:
  - Assets located within CEJEST disadvantaged communities were considered more critical. Disadvantaged communities may not have the same resources as other communities to respond and recover from hazard events. By scoring these communities with higher criticality, the risk assessment can help prioritize resilience improvements for these communities.

3.1.3.4 Risk

Based on the aforementioned indicators, each asset received a score for exposure, sensitivity, and criticality. Risk was then calculated as a function of each asset's exposure, sensitivity, and criticality score for the given hazard. In general, the following risk equation was used:

$$\boldsymbol{Risk} = (Criticality\ Score\ x\ 25\%) + (([Exposure\ x\ 75\%] + [Sensitivity\ x\ 25\%])\ x\ 75\%)$$

Criticality accounted for 25 percent of the overall risk score. Exposure accounted for 75 percent of vulnerability and sensitivity accounted for 25 percent of vulnerability. Overall, vulnerability accounted for 75 percent of the risk score. Each asset received a score of 1 through 4. Assets scoring between 3 and 4 were considered high risk, assets scoring between 2 and 2.99 were considered medium risk, and assets scoring between 1 and 1.99 were considered low risk. The following figures provide examples of how each indicator for exposure, sensitivity, and criticality were incorporated into the risk equation.

Figure 8. Riverine/Coastal Flood Risk Methodology for Roadways

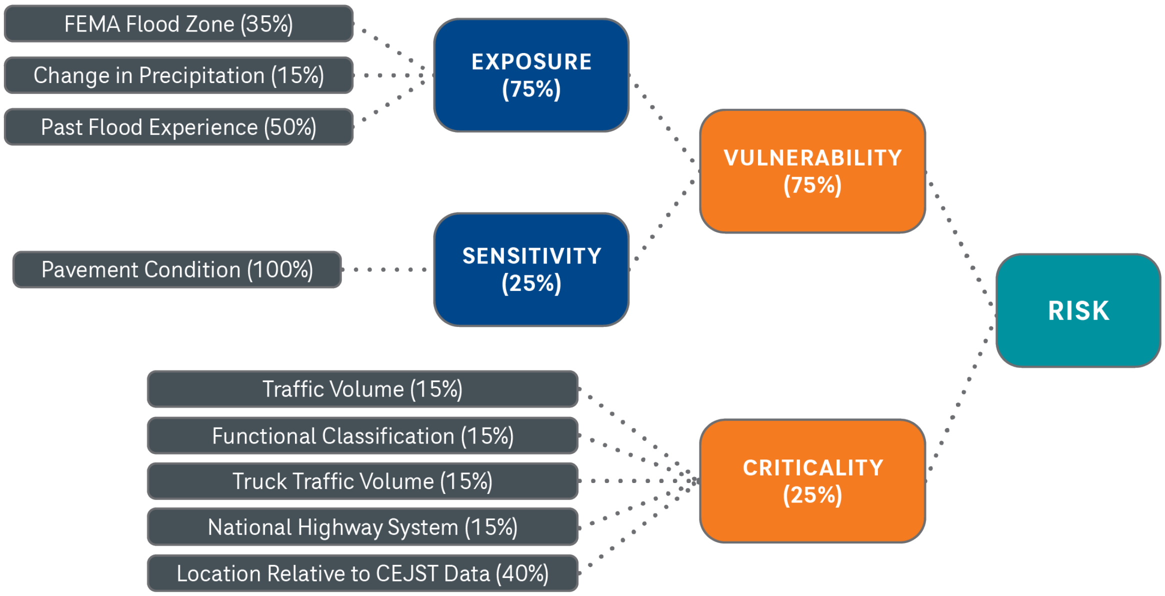


Figure 9. Stormwater Flood Risk Methodology for Roadways

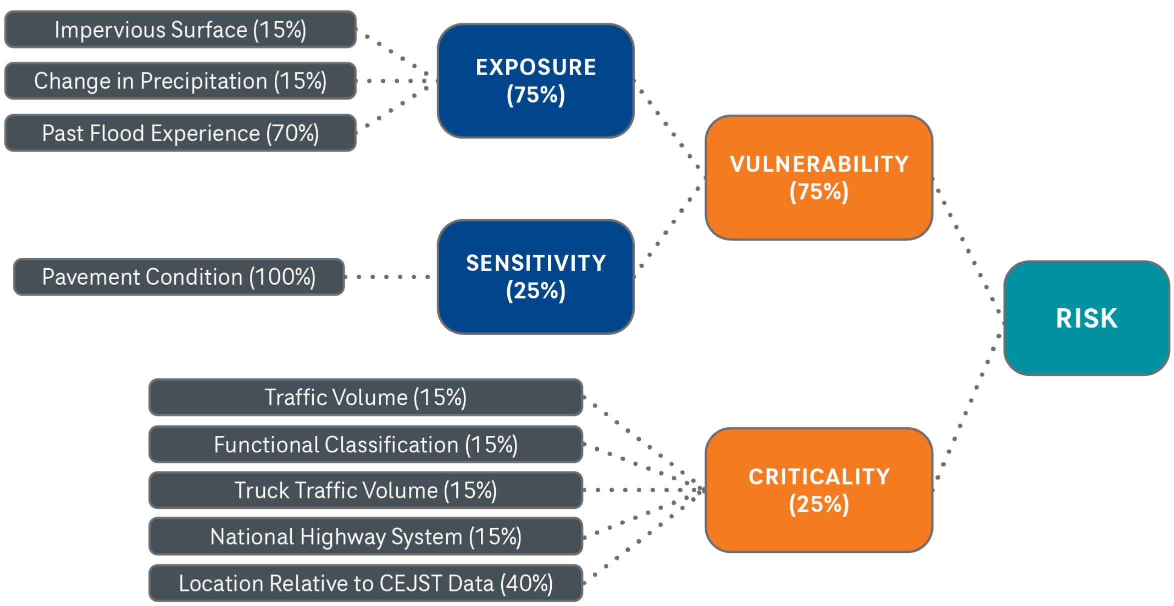
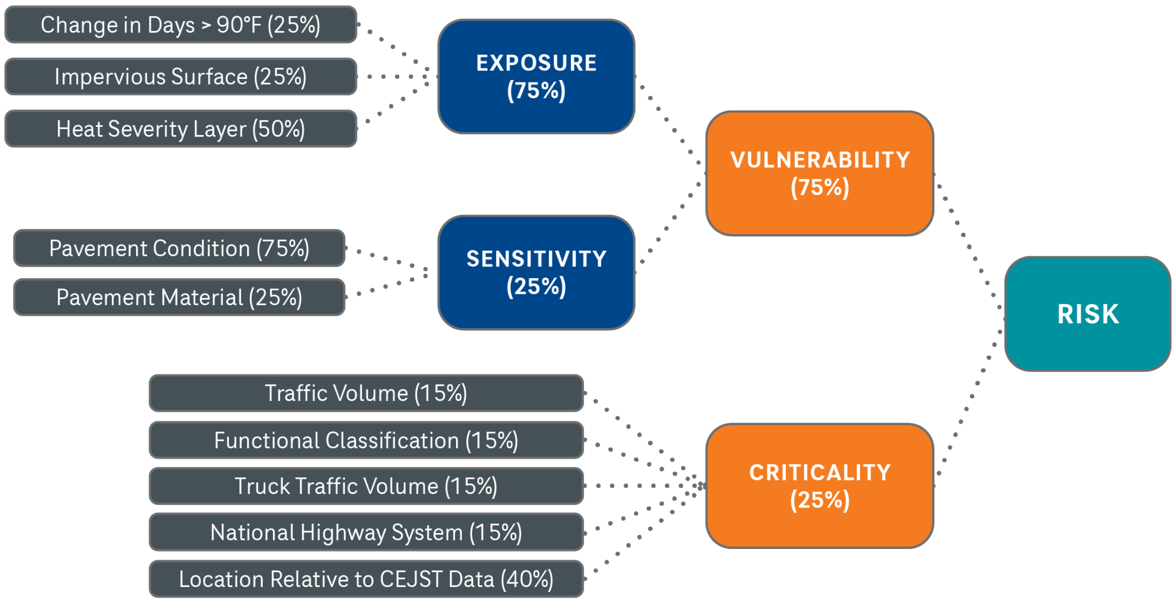


Figure 10. Heat Risk Methodology for Roadways

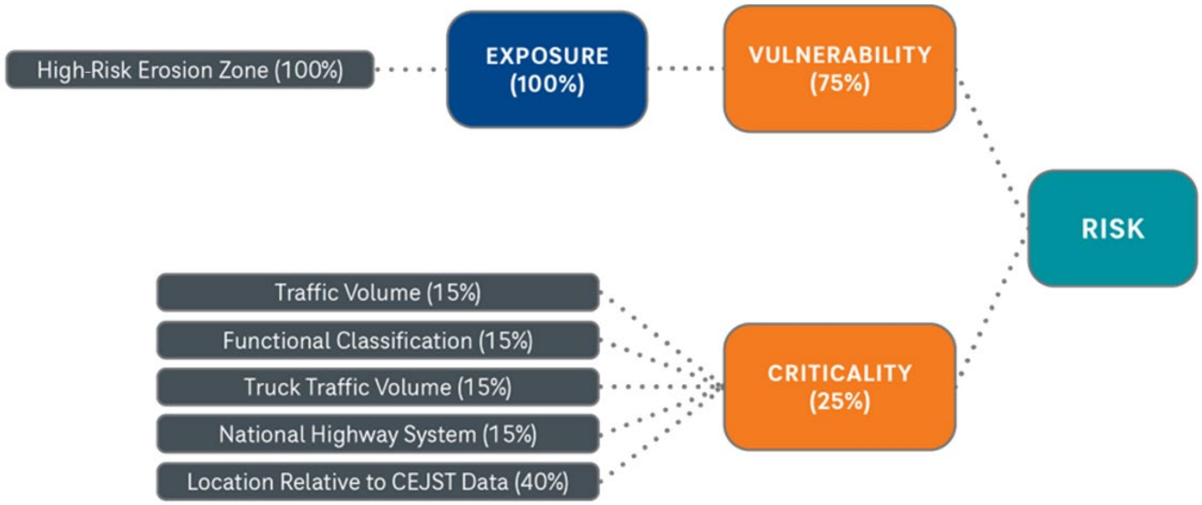


For some risk calculations, no sensitivity indicators were included. These risk calculations used the following risk equation:

$$\textbf{\textit{Risk}} = (Criticality\ Score\ x\ 25\%) + (Exposure\ x\ 75\%)$$

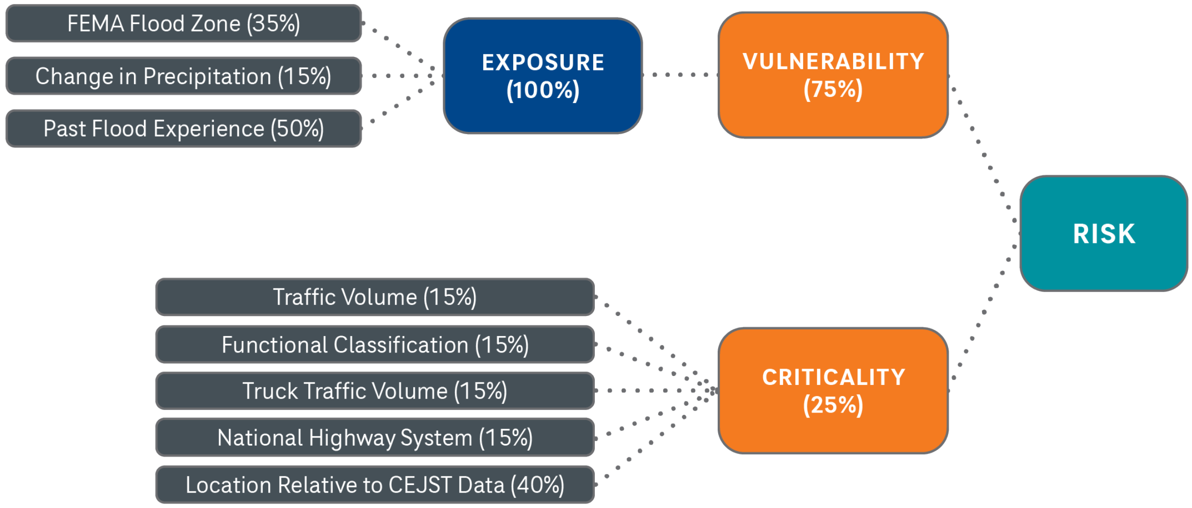
Coastal erosion risk did not include sensitivity indicators based on the assumption that if an asset is located within the High-Risk Erosion Zone, it is equally likely to be damaged regardless of its condition, age, or other sensitivity indicator. **Figure 11** demonstrates the methodology to calculate coastal erosion risk for roadways.

Figure 11. Coastal Erosion Risk Methodology for Roads



The culvert data set was not complete at the time of the risk assessment; therefore, only location information was used to calculate culvert risk. **Figure 12** demonstrates the methodology to calculate riverine/coastal flood risk for culverts. Future iterations of the risk assessment may incorporate the updated culverts database for a more refined understanding of culvert risk.

Figure 12. Riverine/Coastal Flooding Risk Methodology for Culverts



Appendix A presents additional information on the risk assessment methodology. Appendix B presents information on specific data sources.

3.2 Results

Results of the risk assessment are grouped by hazard and asset type. Overall results include both exposure and overall risk. Assets that are the most likely to experience a hazard received a high exposure score, while assets that are also highly sensitive and critical received a high-risk score. This means a particular asset may have a high exposure score (e.g., may experience riverine flooding), but it may not have a high risk score because it was not identified as particularly sensitive (e.g., good condition) and/or was not identified as highly critical (e.g., not located in a disadvantaged community). Understanding which assets have the highest risk can help prioritize project implementation.

Across all hazards, the risk assessment identified roads and bridges as most at-risk to heat with a total of 5,031 roadway segments and 132 bridges with high-risk scores. Culverts were most at-risk to coastal erosion with 34 high risk scores. Pump stations were most at-risk to stormwater flooding with two high risk scores and 126 medium risk scores.

The following subsections provide additional details on the results of the risk assessment for each asset type and each hazard, including location description for the highest risk assets for each hazard.

3.2.1 Riverine/Coastal Flood Results

Riverine and coastal flood risk was assessed for roadways, bridges, culverts, and pump stations. Based on the risk assessment, 223 road segments, 50 bridges, 10 culverts, and one pump station are considered high risk to riverine/coastal flooding. **Table 3** provides a summary of exposure results for riverine/coastal flooding. **Table 4** and **Figure 13** provide a summary of the risk results.

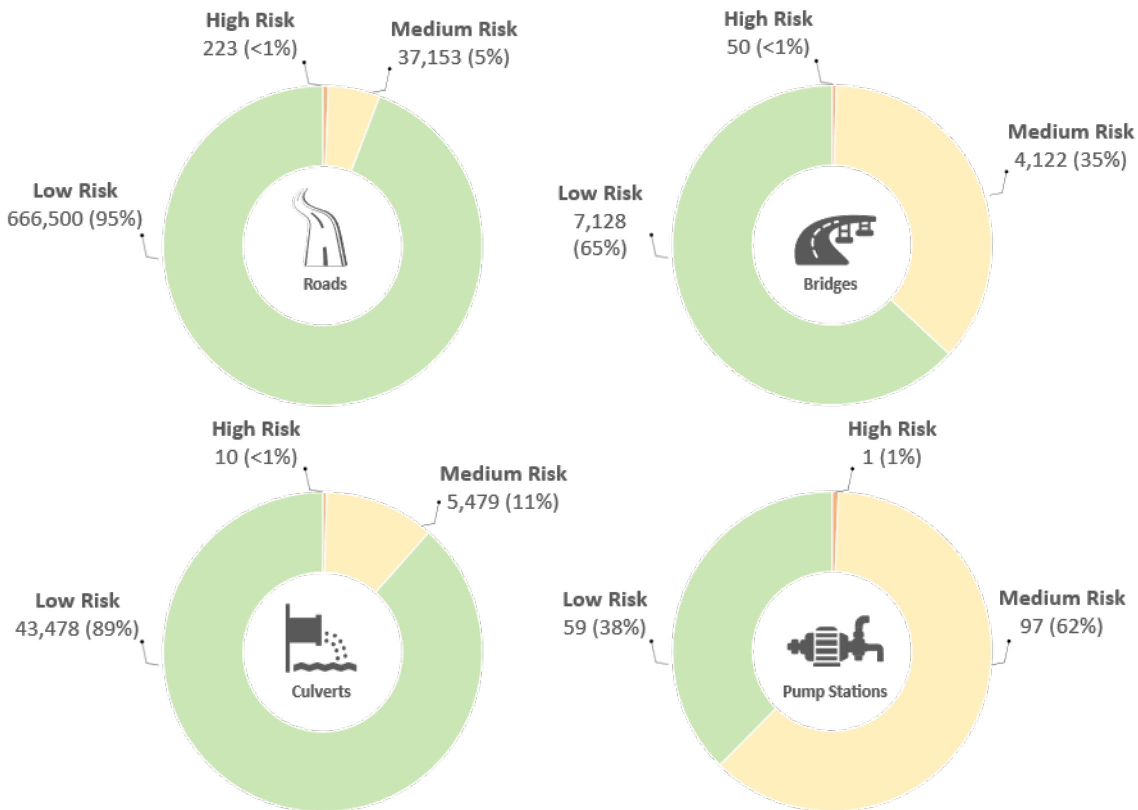
Table 3. Summary Exposure Results for Riverine/Coastal Flooding

Asset Type	Total	Low (Score 1–1.99)	Medium (Score 2–2.99)	High (Score 3–4)
Roadways (Segments)	703,876	666,288 (95%)	37,346 (5%)	242 (<1%)
Bridges	11,300	7,354 (65%)	3,926 (35%)	20 (<1%)
Culverts	48,967	47,098 (96%)	1,859 (4%)	10 (<1%)
Pump Stations	157	151 (96%)	5 (3%)	1 (1%)

Table 4. Summary Risk Results for Riverine/Coastal Flooding

Asset Type	Total	Low (Score 1–1.99)	Medium (Score 2–2.99)	High (Score 3–4)
Roadways (Segments)	703,876	666,500 (95%)	37,153 (5%)	223 (<1%)
Bridges	11,300	7,128 (63%)	4,122 (36%)	50 (<1%)
Culverts	48,967	43,478 (89%)	5,479 (11%)	10 (<1%)
Pump Stations	157	59 (38%)	97 (62%)	1 (1%)

Figure 13. Riverine/Coastal Flooding Risk Results, Number of Assets, and Percentages



3.2.1.1 Top High-Risk Roadways

The following roadway locations are ranked as the highest overall risk to riverine and/or coastal flooding, with scores ranging from 3.72 to 3.96.

1. Hall Road/M-59 over Clinton River in Macomb County near Utica
2. Main Street/M-86 over St. Joseph River in St. Joseph County near Three Rivers
3. East Saginaw Street/M-43 near Grand River in Ingham County near Lansing
4. Outer Drive West and I-75 near Ecorse River in Wayne County near Melvindale
5. I-96 over Rouge River in Detroit/Wayne County

3.2.1.2 Top High-Risk Bridges

The following bridges are ranked as the highest overall risk to riverine and/or coastal flooding, with scores ranging from 3.79 to 3.87.

1. Eastbound on I-69 over Swartz Creek in Genesee County
2. Westbound on I-69 over Swartz Creek in Genesee County
3. Southbound I-75 ramp to I-69 over Swartz Creek in Genesee County
4. I-75 over Swartz Creek in Genesee County

5. US-23/West Center Street over Rifle River in Arenac County

3.2.1.3 Top High-Risk Culverts

The following culverts are ranked as the highest overall risk to riverine and/or coastal flooding, with scores ranging from 3.32 to 3.81.

1. A 36- by 58-inch metal culvert located below South Park Street/M-331 and Crosstown Parkway at Axtell Creek in Kalamazoo County
2. A 15-inch concrete culvert located below Chicago Drive/M-121 near Rush Creek in Ottawa County southwest of the intersection with Port Sheldon Street
3. Two 42- by 60-inch metal culverts located below Chief Noonday Road/M-179 at Glass Creek in Barry County
4. A 15-inch concrete culvert located below US-127 near Sugar Creek in Gratiot County east of the intersection with North Begole Road
5. A 60-inch concrete culvert located below the entrance ramp to US-131 from 54th Street in Kent County near Buck Creek

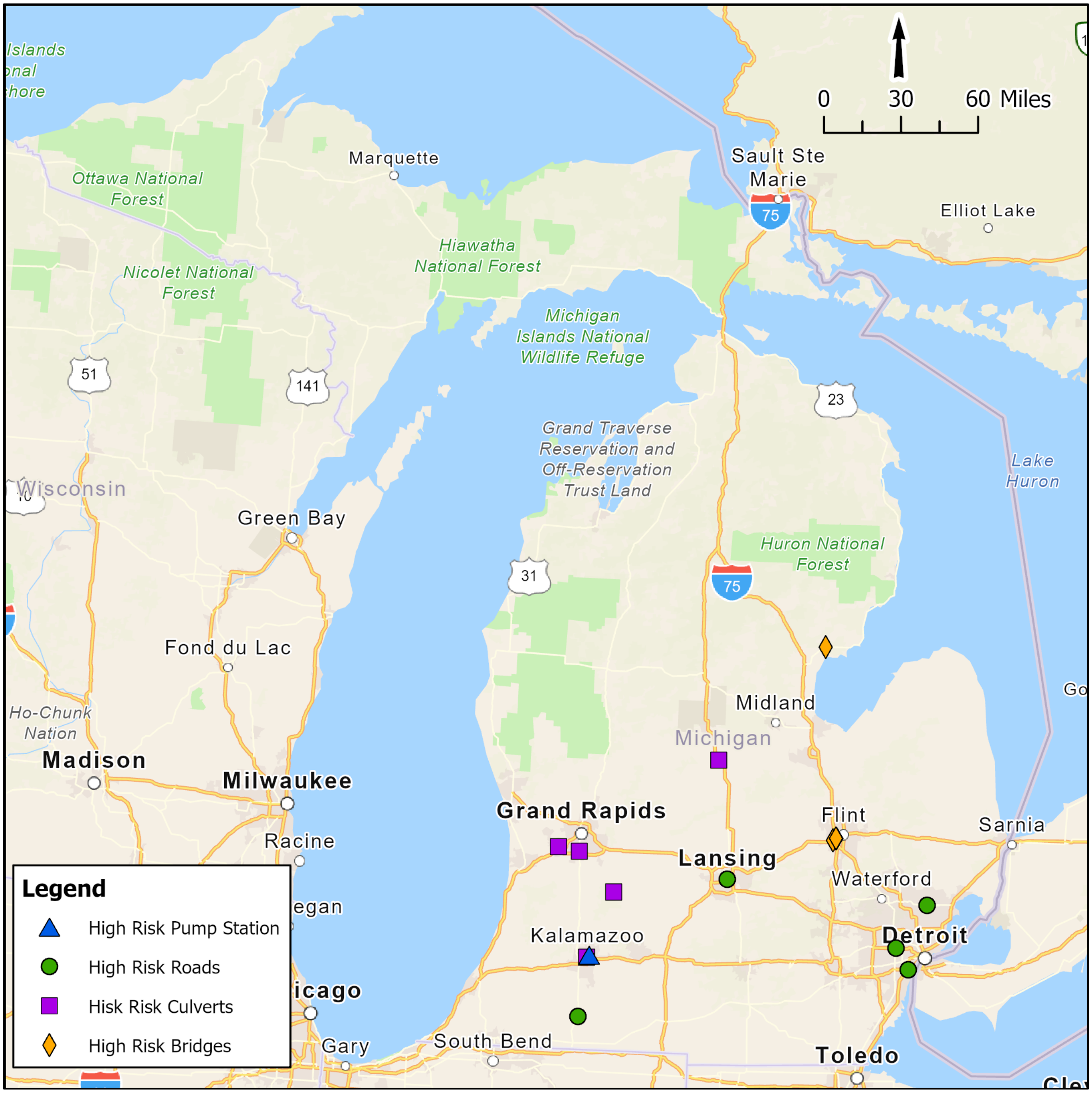
3.2.1.4 Top High-Risk Pump Station

Only one pump station was identified as high risk for riverine and/or coastal flooding, with a score of 3.32.

1. Pump station #3115 located near East Michigan Avenue and Riverview Drive in Kalamazoo County near Kalamazoo River

Figure 14 depicts the locations of the assets with the highest risk to riverine/coastal flooding for each asset type.

Figure 14. Highest Risk Assets to Riverine/Coastal Flooding



3.2.2 Stormwater Flood Results

Stormwater flood risk was assessed for roadways, culverts, and pump stations. Bridges were not assessed for stormwater flooding under the assumption that, in general, stormwater flooding is less likely to occur on bridge decks and more likely to impact roadways below bridges. Additional information would need to be collected to identify bridges that experience stormwater flooding on their bridge decks. Across the state, a total of 965 roadway segments, 18 culverts, and two pump stations were identified as high risk to stormwater flooding. **Table 5** provides the exposure results for stormwater flooding. **Table 6** and **Figure 15** summarize the risk results.

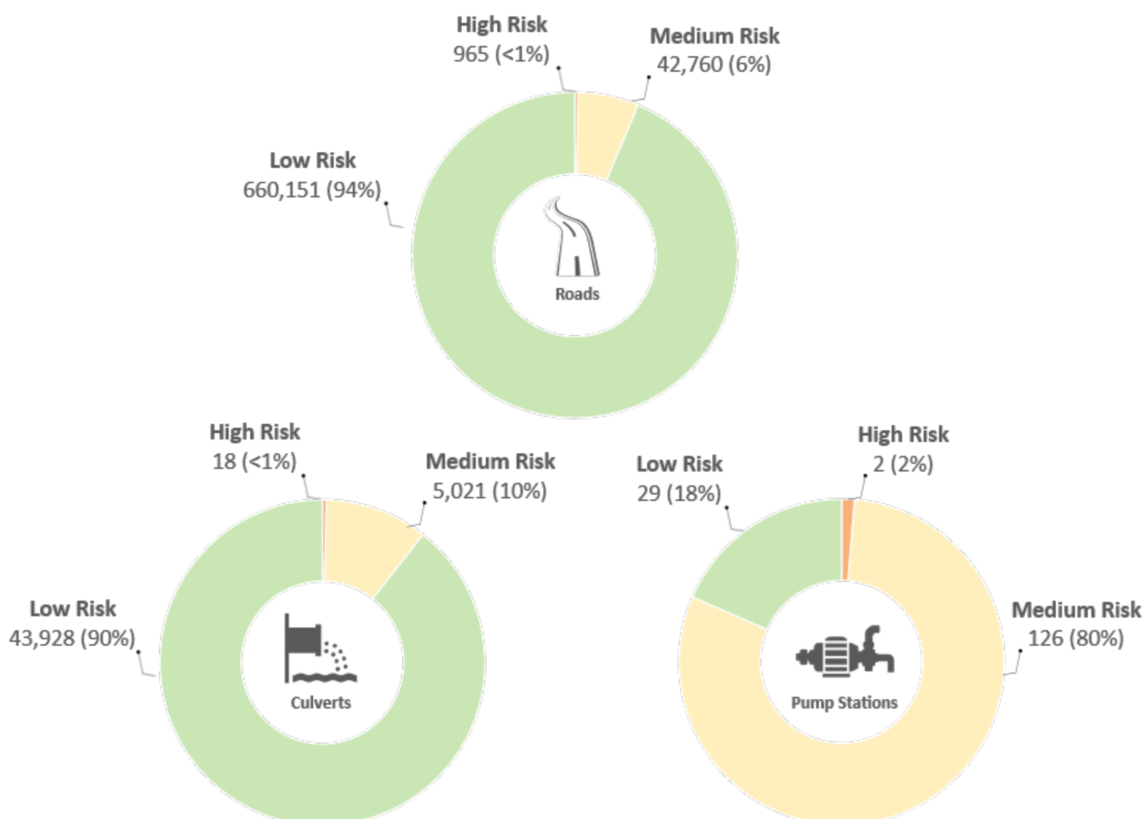
Table 5. Summary Exposure Results for Stormwater Flooding

Asset Type	Total	Low (Score 1–1.99)	Medium (Score 2–2.99)	High (Score 3–4)
Roadways (Segments)	703,876	702,665 (>99%)	0	1,211 (<1%)
Bridges	11,300	N/A	N/A	N/A
Culverts	48,967	48,948 (>99%)	0	19 (<1%)
Pump Stations	157	154 (98%)	0	3 (2%)

Table 6. Summary Risk Results for Stormwater Flooding

Asset Type	Total	Low (Score 1–1.99)	Medium (Score 2–2.99)	High (Score 3–4)
Roadways (Segments)	703,876	660,151 (94%)	42,760 (6%)	965 (<1%)
Bridges	11,300	N/A	N/A	N/A
Culverts	48,967	43,928 (90%)	5,021 (10%)	18 (<1%)
Pump Stations	157	29 (18%)	126 (80%)	2 (2%)

Figure 15. Stormwater Flooding Risk Results, Number of Assets, and Percentages



3.2.2.1 Top High-Risk Roadways

Following are roadway locations ranked as the highest overall risk to stormwater flooding, with scores ranging from 3.78 to 4.

1. I-75 as it crosses below Davison Freeway/M-8 in Detroit near Highland Park
2. I-75 interchange with I-375 near Ford Field in Detroit
3. I-75 interchange with Dix Highway in Lincoln Park
4. I-475 as it crosses below East 2nd Street, East 5th Street, and East Court Street in Flint
5. I-94 as it crosses below John C. Lodge Freeway/M-10

3.2.2.2 Top High-Risk Culverts

Following culverts are ranked as the highest overall risk to stormwater flooding, with scores ranging from 3.48 to 4.

1. A 12-inch metal culvert located below the entrance ramp onto Ecorse Road from I-94 in Taylor
2. An 18-inch concrete culvert located below the entrance ramp from Wayne Road to I-94 in Romulus
3. A 36-inch concrete culvert located below US-31 near the intersection with Fountain Road in Mason County
4. An 18-inch concrete culvert located below M-120 near the intersection with M-82
5. A 12-inch concrete culvert located below I-94 north of the interchange with Red Arrow Highway in Bridgman

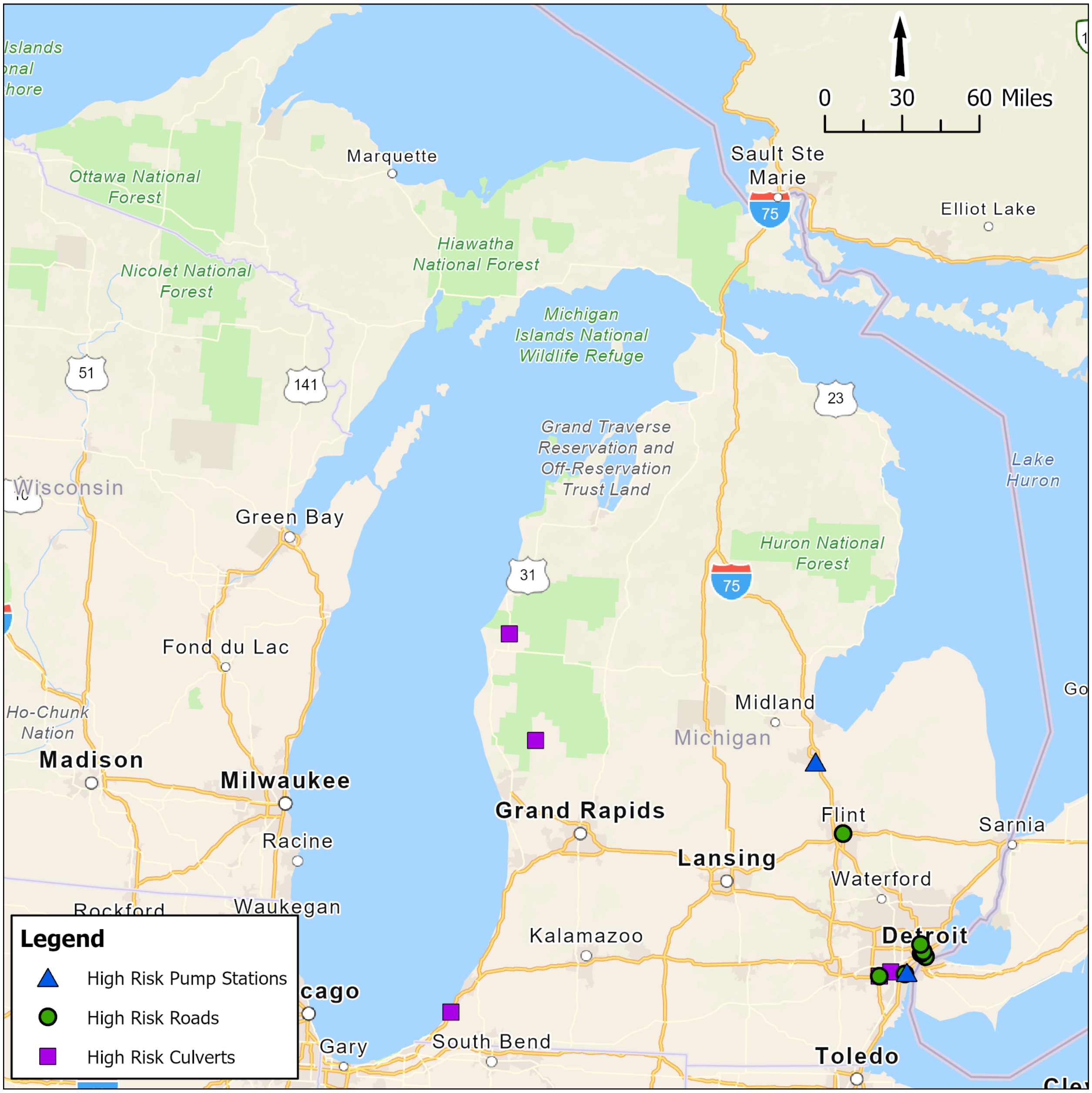
3.2.2.3 Top High-Risk Pump Station

Following are two pump stations ranked as the highest overall risk to stormwater flooding, with scores from 3.22 to 3.44.

1. Pump station #1313 located alongside I-75 near the Cicotte Avenue bridge in Wayne County
2. Pump station #3110 located on the north side of East Holland Road as it passes under the railroad in Saginaw County

Figure 16 depicts the locations of the assets with the highest risk to stormwater flooding for each asset type.

Figure 16. Highest Risk Assets to Stormwater Flooding



3.2.3 Heat Results

Heat risk was assessed for roadway segments and bridges. Pump stations and culverts were not assessed for heat under the assumption that heat impacts to these assets would be minimal. More than 5,000 roadway segments and 132 bridges were identified as high risk to heat impacts. **Table 7** provides the exposure results for heat. **Table 8** and **Figure 17** provide the risk results.

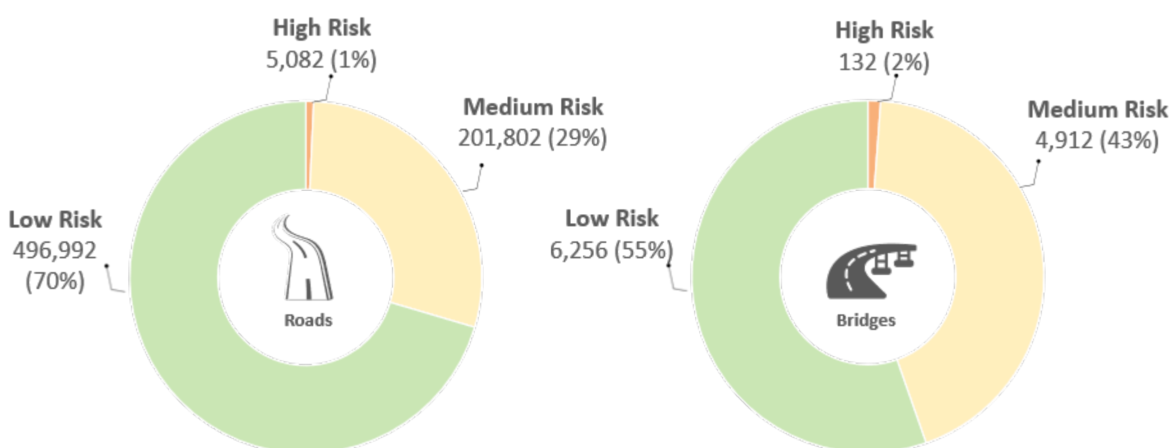
Table 7. Summary Exposure Results for Heat

Asset Type	Total	Low (Score 1–1.99)	Medium (Score 2–2.99)	High (Score 3–4)
Roadways (Segments)	703,876	341,775 (48%)	321,214 (46%)	40,887 (6%)
Bridges	11,300	7,334 (65%)	3,606 (32%)	360 (3%)
Culverts	48,967	N/A	N/A	N/A
Pump Stations	157	N/A	N/A	N/A

Table 8. Summary Risk Results for Heat

Asset Type	Total	Low (Score 1–1.99)	Medium (Score 2–2.99)	High (Score 3–4)
Roadways (Segments)	703,876	496,992 (70%)	201,802 (29%)	5,082 (1%)
Bridges	11,300	6,256 (55%)	4,912 (43%)	132 (2%)
Culverts	48,967	N/A	N/A	N/A
Pump Stations	157	N/A	N/A	N/A

Figure 17. Extreme Heat Risk Results, Number of Assets, and Percentages



3.2.3.1 Top High-Risk Roadways

Following are roadway locations ranked as the highest overall risk to heat, with scores ranging from 3.66 to 3.68.

1. M-97 (Groesbeck Highway and Hoover Street) from the intersection with Prospect Avenue to the intersection with East McNichols Road in Macomb and Wayne Counties
2. East 13 Mile Road near the intersection with Ryan Road in Macomb County
3. M-3/Gratiot Avenue near the intersection with East 8 Mile Road in Wayne County
4. North Wayne Road near Westland Shopping Center and the intersection with Warren Road in Wayne County
5. Merriman Road near the bridge over I-96 in Wayne County

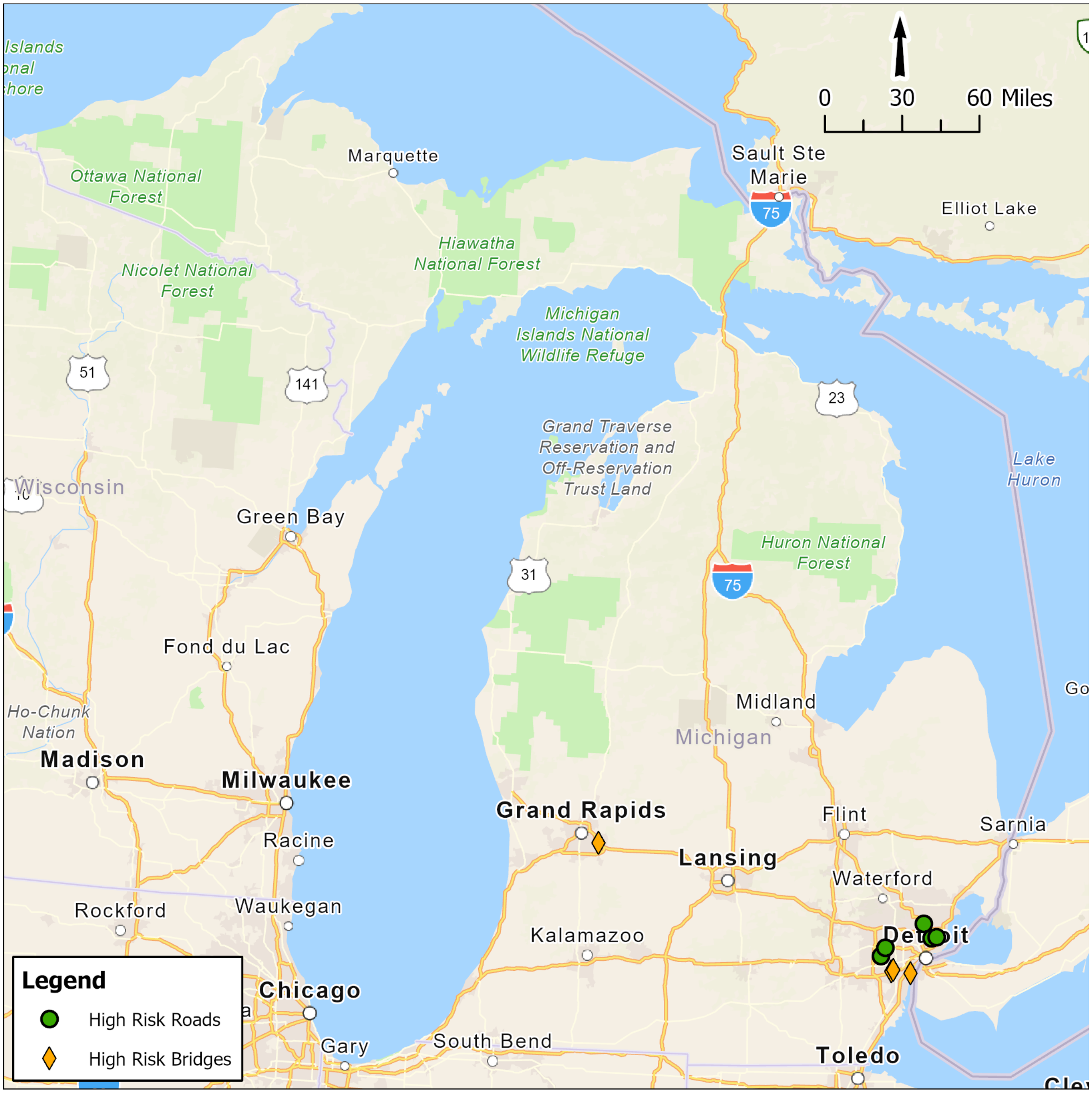
3.2.3.2 Top High-Risk Bridges

Following are bridges ranked as the highest overall risk to heat, with scores ranging from 3.38 to 3.45.

1. Eastbound and westbound on I-96 as it crosses over 28th Street Southeast in Kent County
2. Westbound on I-94 as it crosses Ecorse Road in Wayne County
3. Southfield Road as it crosses Ecorse Creek in Wayne County
4. I-94 Eastbound as it crosses Beech Daly Road in Wayne County
5. North Wayne Road as it crosses Tonquish Creek in Wayne County

Figure 18 depicts the locations of the assets with the highest risk to heat for each asset type.

Figure 18. Highest Risk Assets to Heat



3.2.4 Coastal Erosion Results

Coastal erosion risk was assessed for roadway segments, bridges, culverts, and pump stations. Across the state, 937 roadways segments, two bridges, and 34 culverts were identified as high risk for coastal erosion. No pump stations are located with the high-risk erosion zone; therefore, no pump stations are considered high risk for coastal erosion. **Table 9** provides the summary exposure results for coastal erosion. **Table 10** and **Figure 19** provide a summary of the risk results.

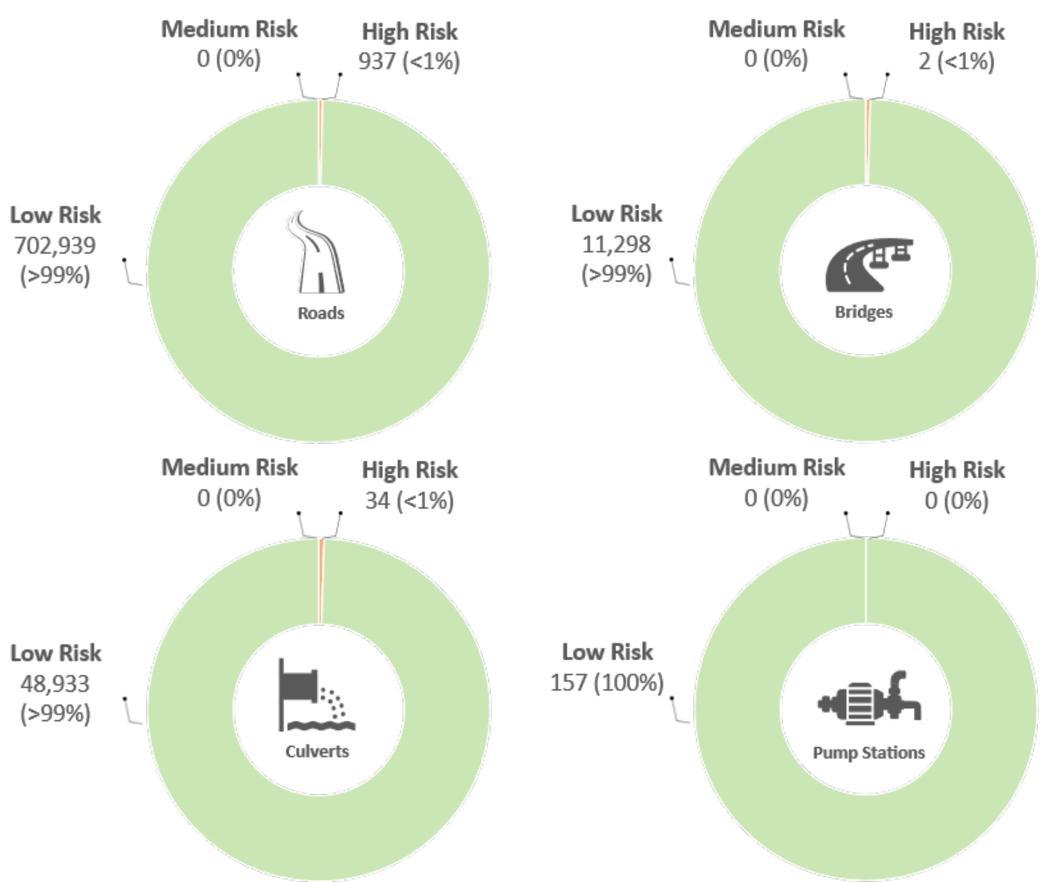
Table 9. Summary Exposure Results for Coastal Erosion

Asset Type	Total	Low (Score 1–1.99)	Medium (Score 2–2.99)	High (Score 3–4)
Roadways (Segments)	703,876	702,939 (>99%)	0	937 (<1%)
Bridges	11,300	11,298 (>99%)	0	2 (<1%)
Culverts	48,967	48,933 (>99%)	0	34 (<1%)
Pump Stations	157	157 (100%)	0	0

Table 10. Summary Risk Results for Coastal Erosion

Asset Type	Total	Low (Score 1–1.99)	Medium (Score 2–2.99)	High (Score 3–4)
Roadways (Segments)	703,876	702,939 (>99%)	0	937 (<1%)
Bridges	11,300	11,298 (>99%)	0	2 (<1%)
Culverts	48,967	48,933 (>99%)	0	34 (<1%)
Pump Stations	157	157 (100%)	0	0

Figure 19. Coastal Erosion Risk Results, Number of Assets, and Percentages



3.2.4.1 Top High-Risk Roadways

Following are roadway locations ranked as the highest overall risk to coastal erosion, with scores ranging from 3.85 to 3.96.

1. US-41 from the intersection with Mission Road to Bear Town Road in Baraga County
2. US-23 from the intersection with 9th Avenue to the intersection of Pine Street in Iosco County
3. US-23 from the intersection with Tac Trail to the intersection of Huron Street in Iosco County
4. US-2 from North Brevort Lake Road to just south of the intersection with Lake Head Road in Mackinac County
5. Lakeshore Road between the intersection with Applegate Road and French Line Road in Sanilac County

3.2.4.2 Top High-Risk Bridges

Following are two bridges ranked as high risk to coastal erosion, with scores ranging from 3.33 to 3.36.

1. Scenic Drive over Duck Lake Channel in Muskegon County
2. Lake Road over Omans Creek in Gogebic County

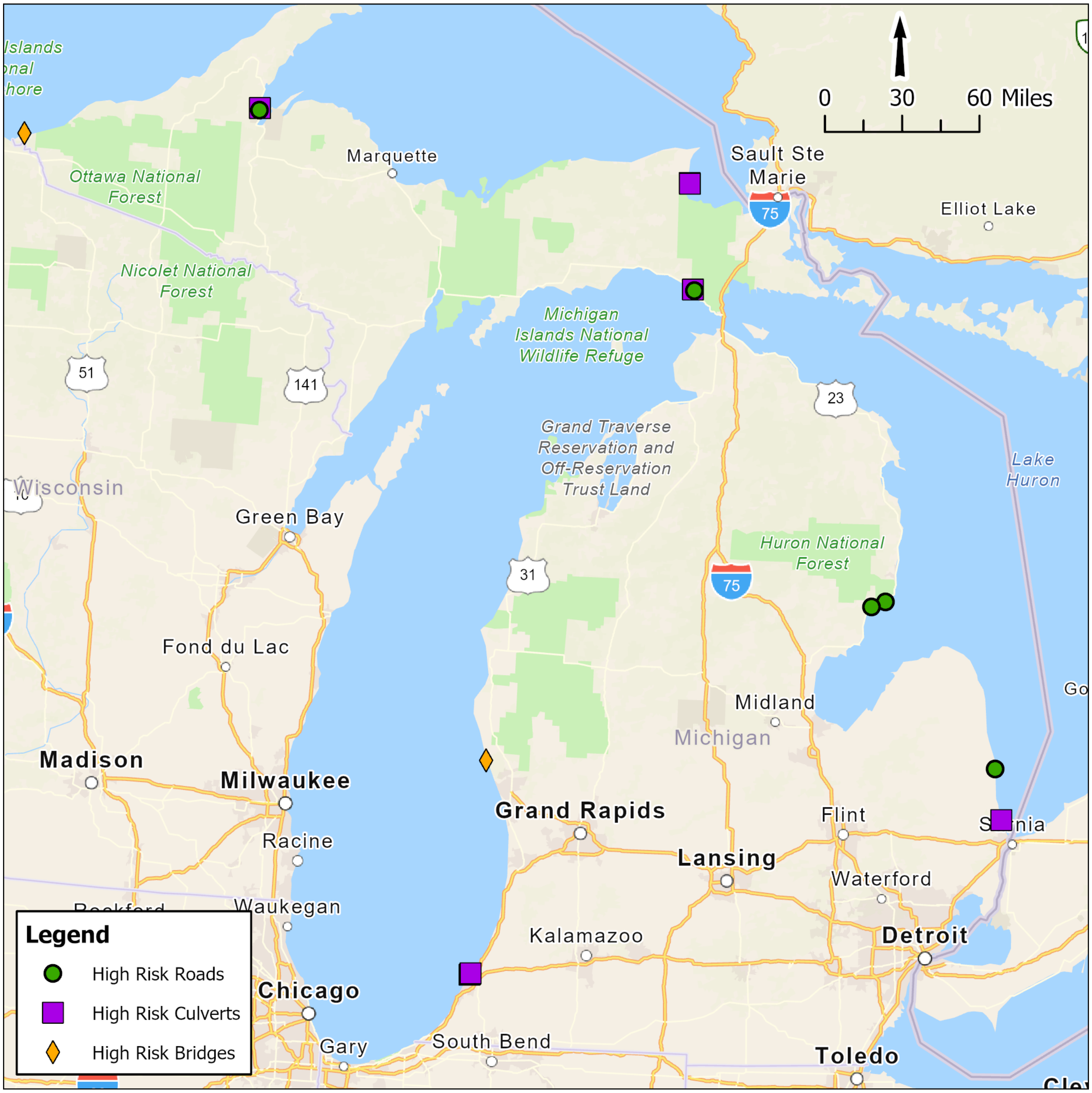
3.2.4.3 Top High-Risk Culverts

The following culverts are ranked as the highest overall risk to coastal erosion, with scores ranging from 3.66 to 3.96.

1. Two 24-inch concrete culverts located below US-41 south of the intersection with Bear Town Road in Baraga County
2. A 24-inch concrete culvert located below US-2 southeast of the intersection with Lake Head Road
3. Four 12-inch concrete culverts running parallel to M-63 between Benson Road and Zoschke Road in Berrien County
4. Two 24-inch concrete culverts and a 30-inch by 36-inch concrete culvert located below M-123 north of the intersection with West Tahqua Trail
5. A 36-inch metal culvert located below Lakeshore Road in St. Clair County

Figure 20 depicts the locations of the assets with the highest risk to coastal erosion for each asset type.

Figure 20. Highest Risk Assets to Coastal Erosion



4.0 Resilience Improvement Strategies

MDOT identified seven strategies to improve the resilience of transportation infrastructure from the four assessed climate hazards: (1) riverine/coastal flooding, (2) stormwater flooding, (3) coastal erosion, and (4) extreme heat. Various types of strategies were identified to meet the diverse needs across the state of Michigan and include structural, non-structural, natural and nature-based, policy and planning, community engagement and education, and operations and maintenance solutions.

Each strategy includes potential actions that may be taken based on the type of infrastructure (i.e., roadways, bridges, culverts, and pump stations) and context of the surrounding environment (i.e., density of development). In addition to improving resilience, these strategies provide co-benefits, such as improving air quality or reducing long-term costs, allowing MDOT to meet several objectives through strategy implementation. This section identifies each strategy and the associated potential actions, hazard, asset type, and co-benefits.

4.1 Green Infrastructure/Nature-Based Solutions

Resilience to flooding, extreme heat, and coastal erosion can be improved by incorporating the use of green infrastructure and nature-based solutions. Green infrastructure and nature-based solutions include the use of vegetation or natural systems such as forests, floodplains, wetlands, and soils to provide benefits for human beings as well as the environment. Green infrastructure and nature-based solutions maximize co-benefits by taking advantage of nature's ability to filter pollutants out of water and the air, supporting ecosystems, and are often considered visually appealing. This strategy includes five potential actions for implementation (**Table 11**).

Table 11. Incorporate the Use of Green Infrastructure/Nature-Based Solutions Potential Actions and Co-Benefits

Potential Actions	Hazards	Assets	Co-Benefits: Improve water quality	Improve air quality	Improve or create green space	Improve aesthetic and visual qualities	Reduce loss of property and reduce substantial damage	Improve localized ecosystems
Tree planting in the right-of-way and to shade assets	Extreme Heat	Road Pump Stations	X	X	X	X		
Use of living shorelines (i.e., using natural materials to stabilize and protect coasts)	Riverine/Coastal Flooding Coastal Erosion	Roads Bridges Culverts	X	X	X	X	X	
Ecosystem restoration (i.e., wetland restoration to protect infrastructure)	Riverine/Coastal Flooding Stormwater Flooding Coastal Erosion	Roads Bridges Culverts	X	X	X	X	X	X
Use of combined natural and hardscape design elements	Riverine/Coastal Flooding Stormwater Flooding Extreme Heat Coastal Erosion	Roads Bridges Culverts	X	X	X	X	X	
Installation of bioretention ponds, bioswales, and rain gardens (i.e., vegetated channels to collect, filter, and carry water)	Stormwater Flooding	Roads	X	X	X	X		X

4.2 Structural Flood and Erosion Resilience Measures

Structural improvements to MDOT's assets can provide increased resilience to flooding and coastal erosion. This strategy includes four potential actions for implementation (**Table 12**). Elements of this resilience strategy are already in progress within MDOT, including recent steps to address pump station power redundancy. MDOT has initiated a process of prioritizing and funding the installation of permanent backup generators at pump stations across the state. The first phase of the effort includes 12 locations in Wayne County.

Table 12. Structural Flood and Erosion Resilience Measures Potential Actions and Co-Benefits

Potential Actions	Hazards	Assets	Co-Benefits			
			Reduce loss of property and reduce substantial damage	Improve safety and reduce potential loss of life in community	Reduce negative business impacts from disruptions in service	Reduce supply chain interruptions
Upgrade pump station equipment to mitigate future flooding impacts and provide backup generators.*	Riverine/Coastal Flooding Stormwater Flooding	Pump Stations	X	X		
Lengthen or raise bridges to increase waterway openings.	Riverine/Coastal Flooding	Bridges	X	X	X	X
Remove, relocate, or elevate assets located within the floodplain.	Riverine/Coastal Flooding Coastal Erosion	Roads Bridges Pump Stations	X	X	X	
Stabilize slopes and/or update slope allowances to reduce erosion risk.	Riverine/Coastal Flooding Coastal Erosion	Roads Bridges Culverts	X	X		X

* Ongoing efforts

4.3 Structural Heat and Resilience Measures

Structural heat and resilience measures can improve the resilience of transportation infrastructure to extreme heat. **Table 13** provides this strategy, which has three potential actions.

Table 13. Structural Heat and Resilience Measures Potential Actions and Co-Benefits

Potential Actions	Hazards	Assets	Co-Benefits		
			Improve safety and reduce potential loss of life in community	Reduce supply chain interruptions	Reduce negative business impacts from disruptions in service
Use bridge joints that can accommodate thermal expansion.	Extreme Heat	Bridges	X	X	X
Increase seat lengths of expansion joints and/or the range of finger joints in bridges.	Extreme Heat	Bridges	X	X	X
Use heat-resistant materials, including heat-resistant asphalt, concrete, or painted roadways.	Extreme Heat	Roads Bridges	X	X	X

4.4 Stormwater Management Infrastructure

Stormwater management infrastructure can improve the resilience of transportation infrastructure to flooding. This strategy includes four potential actions (**Table 14**).

Table 14. Stormwater Management Infrastructure Potential Actions and Co-Benefits

Potential Actions	Hazards	Assets	Co-Benefits			
			Improve safety and reduce potential loss of life in community	Reduce negative business impacts from disruptions in service	Reduce loss of property and reduce substantial damage	Reduce supply chain interruptions
Install stormwater retention basins, drainage systems using basins and sump pumps, pervious pavements.	Stormwater Flooding	Roads Bridges Culverts Pump Stations	X	X	X	
Implement tunnel sewers to eliminate pump stations.	Stormwater Flooding	Pump Stations	X	X	X	

Potential Actions	Hazards	Assets	Co-Benefits: Improve safety and reduce potential loss of life in community	Reduce negative business impacts from disruptions in service	Reduce loss of property and reduce substantial damage	Reduce supply chain interruptions
Increase capacity of stormwater infrastructure (i.e., enlarge culverts, upgrade bridge deck and road drainage systems, replace culverts with bridges).	Riverine/Coastal Flooding Stormwater Flooding	Bridges Culverts	X		X	X
Construct catchment devices upstream of bridges to catch floating debris and minimize effect of debris and ice floes on bridges.	Riverine/Coastal Flooding	Bridges	X	X	X	X

4.5 Resiliency During and After a Disaster

Resiliency during and after a disaster can improve resilience to transportation infrastructure from flooding, coastal erosion, and heat. **Table 15** presents this strategy, which includes six potential actions. As mentioned in Section 4.2, MDOT is in the process of installing permanent backup generators at priority pump stations across the state.

Table 15. Resiliency During and After a Disaster Potential Actions and Co-Benefits

Potential Actions	Hazards	Assets	Co-Benefits: Improve safety and reduce potential loss of life in community	Reduce supply chain interruptions	Reduce negative business impacts from disruptions in service	Reduce loss of property and reduce substantial damages
Develop evacuation routes and redundant routes to access critical facilities/communities.	Riverine/Coastal Flooding Stormwater Flooding Coastal Erosion Extreme Heat	Roads Bridges	X	X	X	

Potential Actions	Hazards	Assets	Co-Benefits: Improve safety and reduce potential loss of life in community	Co-Benefits: Reduce supply chain interruptions	Co-Benefits: Reduce negative business impacts from disruptions in service	Co-Benefits: Reduce loss of property and reduce substantial damages
Encourage and increase the use of emergency communication systems.	Riverine/Coastal Flooding Stormwater Flooding Extreme Heat Coastal Erosion	Roads Bridges	X			
Construct temporary floating bridges if permanent bridges are damaged.	Riverine/Coastal Flooding	Bridges	X	X	X	
Install energy system backup such as generators, batteries, or other alternate sources of power.*	Riverine/Coastal Flooding Stormwater Flooding	Pump Stations	X			X
Deploy backup portable pumps if pump station is not operating.	Riverine/Coastal Flooding Stormwater Flooding	Pump Stations	X			X
Deploy temporary barriers to protect critical assets/ vulnerable communities.	Riverine/Coastal Flooding	Roads Bridges	X		X	X

* Ongoing efforts

4.6 Design Standards and Project Processes

Design standards and project processes can improve resilience to all hazards studied in this plan. **Table 16** presents this strategy, which includes four potential actions. Table 16. Additional recommendations for incorporating climate hazards into design standards are included in Section 6.0. Several ongoing or planned MDOT efforts align with this resilience strategy. The Office of Passenger Transportation is working to incorporate climate projections into project design assumptions. MDOT is also considering developing a checklist to incorporate resilience into the project scoping and selection process.

Table 16. Design Standards and Project Process Potential Actions and Co-Benefits

Potential Actions	Hazards	Assets	Co-Benefits					
			Improve safety and reduce potential loss of life in community	Reduce loss of property and reduce substantial damage	Increase longevity of assets	Reduce long-term costs	Reduce liability risks	Integrate resilience concept through the organization
Require project designs to withstand projections for extreme rainfall, flooding, erosion, and extreme heat.*	Riverine/Coastal Flooding Stormwater Flooding Extreme Heat Coastal Erosion	Roads Bridges Culverts Pump Stations	X	X	X	X	X	X
Develop a checklist for project selection process/project scoping to embed resilience and climate-related planning.	Riverine/Coastal Flooding Stormwater Flooding Extreme Heat Coastal Erosion	Roads Bridges Culverts Pump Stations	X	X	X			X
Incorporate resilience into master planning and capital planning.	Riverine/Coastal Flooding Stormwater Flooding Extreme Heat Coastal Erosion	Roads Bridges Culverts Pump Stations	X	X		X	X	X
Develop resiliency design guidance.	Riverine/Coastal Flooding Stormwater Flooding Extreme Heat Coastal Erosion	Roads Bridges Culverts Pump Stations	X	X	X	X	X	X

* Ongoing efforts

4.7 Monitoring and Maintenance

Tracking and prioritization can improve the resilience of transportation infrastructure to all hazards studied in this plan. This strategy includes six potential actions, see **Table 17**. In line with this resilience strategy, MDOT is in the process of collecting and updating culvert data through the Culvert Asset Management Program.

Table 17. Tracking and Prioritization Potential Actions and Co-Benefits

Potential Actions	Hazards	Assets	Co-Benefits					
			Improve safety and reduce potential loss of life in community	Reduce loss of property and reduce substantial damage	Reduce supply chain interruptions	Increase longevity of assets	Reduce long-term costs	Reduce liability risks
Conduct regular maintenance/inspection and restore infrastructure impacted by and at risk to extreme events.	Riverine/Coastal Flooding Stormwater Flooding Extreme Heat	Roads Bridges	X	X	X	X	X	X
Monitor sagging of large suspension bridges during extreme heat.	Extreme Heat	Bridges	X	X			X	
Conduct routine maintenance of bridge openings, culverts, and storm sewers to remove debris and sediment.	Riverine/Coastal Flooding Stormwater Flooding	Bridges Culverts	X	X	X	X	X	
Install sensor systems along or within assets to monitor for water level and changing climate conditions.	Riverine/Coastal Flooding Stormwater Flooding Extreme Heat	Bridges Culverts	X	X				
Track asset conditions to determine those vulnerable/damaged from extreme events; prioritize projects that reduce infrastructure damage and failure.*	Riverine/Coastal Flooding Stormwater Flooding Extreme Heat Coastal Erosion	Roads Bridges Culverts Pump Stations	X	X	X	X	X	X
Continue the Culvert Asset Management Program to track culvert condition, size, material, and age.*	Riverine/Coastal Flooding Stormwater Flooding	Culverts	X	X	X	X	X	X

* Ongoing efforts

5.0 Cost Breakdown

The following section provides order of magnitude costs for the resilience strategies and proposed actions selected for this Resilience Improvement Plan. The following cost estimates are illustrative examples of proposed actions that could be implemented under each resilience strategy and were chosen based on data availability.

Cost estimates were developed based on literature review, qualitative evaluation, and/or engineering estimates.[xli] **Table 18** provides cost estimates, the project stage, and any assumptions.

Values were adjusted from source data to account for inflation and reflect 2024 prices.

Table 18. Cost Estimates for Resilience Improvement Strategies and Proposed Actions

Strategy	Cost Estimate	Type of Hazard			Project Stage	Assumptions
		Flooding	Heat	Coastal Erosion		
Tree planting in the right-of-way and to shade assets	$368 per tree		X		Design, Operations and Maintenance (O&M)	Two sides of the road at 10-foot intervals.
Use of living shorelines	$26–$2,671 per 1,000 feet of shoreline with $11,955–$179,332 for mobilization and demobilization	X		X		Range is based on a variety of cost factors, including but not limited to staging/access, water/land construction, site preparation, and establishment of vegetation species.
Ecosystem restoration (i.e., wetland restoration to protect infrastructure)	$74,129 per acre	X			Policy, Design	
Installation of bioretention ponds, bioswales, and rain gardens	$211,728 per acre	X			Design	
Stabilization of slopes and/or update of slope allowances to reduce erosion risk	$521 per linear foot	X		X	Design, O&M	

Strategy	Cost Estimate	Type of Hazard			Project Stage	Assumptions
Increased seat lengths of expansion joints and/or the range of finger joints in bridges	18% of building replacement cost (BRC)		X		Design	
Use of heat-resistant materials, including heat-resistant asphalt, concrete, or painted roadways	$37 per linear foot per track		X		Policy, Design, O&M	
Installation of stormwater retention basins	$306,319 per acre	X			Design	
Installation of drainage basins and sump pumps	$2,267 per pump	X			Design, O&M	
Installation of pervious pavement	$673,903 per acre	X			Design	
Enlargement of culverts	$1,225,277 per culvert	X			Design, O&M	
Replacement of culverts with bridges	$551 per square feet	X			Design	
Upgrade of bridge deck and road drainage system	$306,319 per acre	X			Design	
Installation of sensor systems along or within assets to monitor for water level and changing climate conditions	10% of (BRC)		X		Design, O&M	Proactive scenario assumes the cost of the sensor alone. Operational costs vary significantly. Retroactive scenario assumes the need for extensive repairs because of a lack of monitoring.
	$306,319 per lane mile		X		Design, O&M	Proactive scenario assumes that the lack of monitoring will lead to damages and the need to resurface the road.
	$18,379 per 10 miles of roadway	X			Design, O&M	

6.0 Roadmap for Implementation

Michigan outlines the goals and objectives within the MM2045 Plan that relate to building climate change resilience into the state's transportation system. As mentioned in Section 1.0, PROTECT funds can be used to increase the resilience of surface transportation assets, communities, coastal infrastructure, and natural infrastructure. Based on the goals of MM2045 and the purpose of the PROTECT Program funds, this Resilience Improvement Plan identifies the following short-, mid-, and long-term goals.

- Short-term goals:
  - Identify and prioritize projects that improve the resilience of surface transportation facilities to climate hazards in Michigan.
  - Incorporate resilience strategies into existing processes, procedures, and design manuals.
  - Prioritize project locations that reduce risks to and improve access for disadvantaged communities.
- Medium-term goals:
  - Secure funding sources for prioritized projects.
  - Implement projects that improve the resilience of surface transportation facilities to climate hazards in Michigan.
- Long-term goals:
  - Build a transportation system that is prepared for, can withstand, and recover from the hazards associated with climate change.
  - Reduce risks associated with climate hazards.
  - Maintain safe and effective transportation throughout Michigan.
  - Ensure continued access to homes, businesses, essential services, and critical facilities.
  - Reduce long-term costs by avoiding future damage, maintenance, and reconstruction over a project's useful life.

Achieving these goals will require a systematic and ongoing approach across the state and in partnership with Tribal nations and local governments. This plan should be considered a living document and MDOT may adapt it as needed. Along these lines, the risk assessment should be an iterative process that can be updated and refined as additional data become available and climate conditions change. Recommendations outlined in this roadmap will help MDOT ensure that the information from this plan is integrated into other planning processes, funding priorities, and decision-making across the state. Moving beyond project implementation, this Roadmap provides recommendations on monitoring and evaluating project success toward achieving the aforementioned goals.

6.1 Integrating Resilience into Transportation Planning

Implementation of this Resilience Improvement Plan results and recommendations requires integration across three main categories: 1) the state's planning, polices, and standard procedures; 2) the state's infrastructure to address critical needs identified in the risk assessment; and 3) the use of technology to reduce risks.

6.1.1 Planning, Policies, and Standards

Integrating the results of this Resilience Improvement Plan into existing planning processes and integrating resilience into policies and standards helps ensure that this plan provides actionable and tangible results and achieves its overall purpose in supporting MDOT to reduce risk and increase resilience.

The following are recommendations for integration opportunities. For each of the following planning processes, MDOT may consider working with the groups involved in the development and implementation of these plans and programs and coordinate the incorporation of this Resilience Improvement Plan's goals, risk assessment results, and resilience strategies.

- **Incorporate project locations identified through this Resilience Improvement Plan into the next annual update of the MDOT Five-Year Transportation Program.**[xlii] Work with staff responsible for updating the Program to align goals, investments, and areas of interest.
- **Use the existing partnerships and stakeholder network developed through the creation of the Michigan Mobility 2045 Plan to leverage results and recommendations of this Resilience Improvement Plan.**[xliii] Promote internal education and communication on how this Resilience Improvement Plan strategies support the goals of the MM2045 Plan to gain support across the department.
- **Incorporate the Resilience Improvement Plan findings and recommendations into future Transportation Asset Management Plan development.**[xliv] This Resilience Improvement Plan used the July 2022 TAMP as a starting point in its development of goals and hazard selection. The TAMP is required to be updated every 4 years.
- **Update engineering design manuals to account for climate change hazards.** Existing engineering design manuals may be updated to include climate resilience specifications. MDOT may also develop new climate resilience design guidance for specific hazards.
- **Require the inclusion of resilience projects and initiatives into capital planning procedures.** Embed the Risk and Resilience Online Screening Tool into the capital planning process and use the tool in project planning and prioritization. The tool is based on the risk assessment described in Section 3.0 and provides readily accessible data on the exposures, vulnerabilities, and risks associated with transportation assets across the state. Trainings could be provided to inform planning authorities and project proponents of the map's use in identifying at-risk assets, high-risk locations, and vulnerabilities (exposures and/or sensitivities) to consider. The risk and vulnerability associated with a project site could inform the need for risk-appropriate design.
- **Incorporate resilience criteria into project funding frameworks**, such as the **State Transportation Improvement Program,** to identify and prioritize projects that align with the resilience improvement strategies. This may be implemented in the form of a screening checklist

or scoring method. Criteria integrated into funding frameworks may also assist MDOT in tracking implementation over time.[xlv]

Integrating resilience into MDOT's planning processes, standards, and policies helps ensure that resilience is not seen as any one project but as a fundamental piece of how MDOT operates and implements projects across the state.

6.1.2 Infrastructure

The outcomes of the Resilience Improvement Plan risk assessment identify critical infrastructure needs across the state. These needs can be considered on a geographic/community level, by hazard, or by asset type. Implementation processes may differ based on how MDOT chooses to consider these risks.

- **Focus on solutions that address recurring issues or patterns of risk.** Patterns in the results of the risk assessment highlight some key critical infrastructure issues and needs across the state.
    - Stormwater flooding risk predominantly occurs when a major roadway/interstate reduces grade to cross below a bridge. Limited or aging stormwater infrastructure cannot keep up with high rainfall rates and when significant ponding under these bridges occurs.
    - Heat risk occurs predominantly on highly trafficked but poorly maintained roadways in disadvantaged communities where temperatures are higher relative to the rest of the city, roadway conditions are poor, and pavement materials are more sensitive to buckling. Unlike major interstates in the region, these roadways likely have been neglected historically.
    - Riverine flooding in the state predominately occurs when culverts or bridges are undersized, or river channels are confined by development.
- **Use a consistent and up-to-date data management system in operations and maintenance procedures.** Track asset condition and prioritize maintenance schedules based on the asset vulnerabilities and potential risks identified within the risk assessment. Consistent data management can also inform future risk assessments.
- **Improve data collection for future tracking and implementation needs.** Specific data collection efforts should reflect the identification and selection of indicators and metrics, as mentioned above. Potential data collections efforts may include:
    - Increased information related to past flood events, such as the number of impact days, flood source (riverine, stormwater, high lake levels, dam failure), flood elevation, length of detour, damage costs, and communities or residences impacted
    - Heat impact information, such as location, pavement material, pavement response, air temperature, heatwave length in days, damage costs, length of detour, pump station impacts, and impact days
    - Detailed culvert information based on MDOT's Culvert Asset Management Program (in progress at the time of this report), including data on culvert condition, age, material, and size

6.1.3 Technology

MDOT may consider increasing transportation resilience using new technology in construction and monitoring systems, as well as through pilot programs.

- **Use sensors to track climate hazards and changing conditions**, such as water levels or pavement surface temperature to better predict when infrastructure may be at risk. This can allow for emergency intervention to prevent damage and/or proactive infrastructure closures.
- **Use closed-circuit television (CCTV) technologies for culvert inspections.**
- **Use new technology for construction**, such as heat-resistant materials, pervious pavement, and innovative green infrastructure technologies.
- **Determine appropriate applications using pilot technologies.** MDOT may consider implementing pilot projects to determine the most appropriate applications of certain technologies. Pilot projects may include a collection of pre- and post-implementation data, such as the surface temperature of pavement, to confirm that the use of heat-resistant materials sufficiently reduces the impact of extreme heat. Similarly, MDOT may consider implementing pilot projects for the use of living shorelines to address coastal erosion. Living shoreline pilot projects may help MDOT determine the appropriate schedule and costs of maintenance while living shoreline vegetation is becoming established. In addition, pilot projects may provide MDOT with data on the most effective combination of natural and structural measures based on slope, wave action, and intended co-benefits of a project area.

Michigan's climate hazards are changing, but the technologies available to address those hazards are changing too. Staying up to date on available technologies, implementing pilot programs, and using new methods and materials has the potential to help Michigan adapt to the changing conditions.

6.2 Funding and Resources

MDOT may consider leveraging existing funding opportunities and coordinating with other state initiatives to increase the department's capacity to implement resilience projects.

- **Use PROTECT Program funds.**[xlvi] In addition to the development of a Resilience Improvement Plan, PROTECT Program funds may be used for eligible resilience improvement activities, such as the strategies and proposed actions identified within this plan, building community resilience through increased access to critical destinations, and protecting at-risk coastal infrastructure.
- **Coordinate resilience projects with the efforts identified in MDOT's Carbon Reduction Strategy**, such as pavement preservation and using intelligent transportation systems to communicate traffic incidents such as closures associated with flooding. Combining the efforts of MDOT's Carbon Reduction Strategy with resilience improvement strategies may allow MDOT to leverage funding through the Carbon Reduction Program (23 U.S.C. 175 § 11403).[xlvii]
- **Coordinate funding opportunities across state agencies and localities.** Identify opportunities to align with other state agency initiatives to access additional sources of funding. Examples include:

  - FEMA Region 5 Mitigation Assistance Resource Guide – State of Michigan provides information on potential sources of funding and/or technical assistance for mitigation.[xlviii]
  - Michigan State Coastal Zone Management Program website compiles applicable funding sources for coastal projects under "Open Grant Funding Opportunities."[xlix]

While funding specific to improving transportation resilience does exist, it is limited. Working resilience into existing initiatives and identifying overlaps across state and federal programs may help ensure Michigan can meet its resilience goals.

6.3 Partnerships and Collaboration

MDOT may consider continuing to foster partnerships and collaboration at the local, regional, and state levels. Implementing resilient strategies takes interagency collaboration and many public–private partnerships, as well as trusted partnerships with nongovernment organizations (NGOs), metropolitical planning organizations, rural planning organizations, and more. Combined with best practices for equitable engagement with disadvantaged communities and training, partnership building may further help institutionalize new ways of transportation planning.

- Share knowledge, experience, and data with partner agencies, metropolitan planning organizations, or rural planning organizations.
- Coordinate resilience efforts with the Michigan Emergency Management and Homeland Security Department.
  - Incorporate guidance from the NCHRP's Emergency Management Playbook for State Transportation Agencies to improve MDOT's ability to prepare for, respond to, and adapt to existing, new, or changing hazards.[l]
  - Collaborate on next iteration of the Michigan State Hazard Mitigation Plan to determine overlaps in needs, resilience strategies, and mitigation actions. The updated Hazard Mitigation Plan should reference this Resilience Improvement Plan and build off its data and results.[li]
    - Align resilience implementation efforts with the Michigan Citizen-Community Emergency Response Coordinating Council.[lii] Present the results of this Resilience Improvement Plan at the committee's regularly scheduled meetings.
- Coordinate resilience efforts with Michigan's Bureau of Bridges and Structures, MDOT's Ancillary Structures Unit, the Michigan Infrastructure Commission, Transportation Asset Management Council, Water Asset Management Council, and County Drain Commissioner Offices.
  - Incorporate the findings of the recently completed a statewide culvert conditions assessment by the Transportation Asset Management Council.
  - Incorporate the findings of the Bureau of Bridges and Structures bridge-specific risk assessment.
- Work with the MI State Coastal Zone Management Program manager to better understand the program's goals and resources.[liii] MDOT may refer to the Resilient Coastal Communities Planning

Guide in the development and implementation of projects to confirm alignment with Michigan Coastal Management Program's Pathway to Resilience.[liv]

Aligning goals and resilience efforts at the local, state, and regional levels may help ensure future initiatives are building off previous work, reducing the duplication of efforts, and encouraging coordination across the state. When efforts are aligned and strong partnerships are in place, implementation success is more achievable.

6.4 Monitoring and Evaluation

Tracking the success, impacts, and outcomes of resilience efforts has been a challenge for state transportation agencies. Documenting that resilience strategies are providing benefits to communities may increase the likelihood of future availability of funding and support, build support for future resilience efforts, help plan for future investments, and contribute to the growing body of research on successful resilience methods.[lv] Following are descriptions of potential methods of tracking resilience projects, the use of resilience metrics and indicators in evaluation, and the importance of adaptive management.

6.4.1 Tracking Resilience Projects

To understand whether projects are providing their intended benefits, MDOT may consider establishing a consistent method of tracking project data. Possible tracking methods may include:

- **Using the risk assessment data as a starting point, building an all-encompassing geographic information system (GIS)-based platform to map climate risks and resilience projects** (including project costs). Regularly assess how assets faired in comparison to extreme weather and climate events. Regular updates to the database may help MDOT identify which investments have been most successful and which risk areas need additional focus.
- **Creating pre- and post-project analysis checklists to record the performance of a project and associated resilience improvement strategy.** This analysis may help identify whether particular strategies function best under certain circumstances and/or achieve higher levels of risk reduction/resilience to climate hazards.

MDOT may also consider establishing a system to capture and share lessons learned. This potentially could improve communication both internally and externally regarding which efforts have been most successful and what has been challenging.

6.4.2 Resilience Metrics and Indicators

An important aspect of evaluating the success of a resilience project is defining what success means to MDOT, the state, and/or individual communities. The development of indicators and metrics can help specify what the tangible goal of the project (or suite of projects) is and identify how that goal can be measured.

ResilienceMetrics.org provides guidance on the process of identifying indicators and metrics to help track the implementation success. The site defines an *indicator* as "a sign that a particular set of adaptation actions are yielding the desired result and/or making progress in the right direction." *Metric* is "a variable that can be measured (if quantitative) or otherwise tracked (if qualitative) that represents the indicator." **Table 19** provides examples of potential indicators and metrics for tracking the success of MDOT's resilience initiatives.

Table 19. Example Indicators and Metrics for Resilience Initiatives

Hazard	Indicator	Metric
Riverine Flooding	Reduced flood damage to roadways	Comparison of pre-project flood damages ($) to post-project flood damage
Stormwater Flooding	Reduced long-term maintenance and repair costs to stormwater system	Comparison of annual maintenance costs each year as resilience strategies are implemented
Heat	Reduced impacts to communities from impassable roads	Number of days per year with road closures because of heat impacts
Coastal Erosion	Reduced impacts to critical roadways located within the High-Risk Erosion Zone	Number of miles of critical roadways elevated or rerouted out of High-Risk Erosion Zone

MDOT discussed resilience indicators and metrics during the final Regional Stakeholder Working Group meeting (Section 1.3). During the meeting, stakeholders identified an overarching indicator of reduced negative impacts on transportation system users (e.g., not having to close bridges during flood events, reducing culvert and road washouts during flood events). Stakeholders also emphasized the benefit of using data that are already collected as metrics, such as the cost of repairs and damage, and coordinating existing data across departments. MDOT may consider hosting additional brainstorming sessions with stakeholders to further collaborate on what these indicators and metrics should be for the department, the state, or specific communities impacted by climate hazards, as well as ensure that the correct data collection processes are in place to measure those selected.

6.4.3 Adaptive Management

Adaptive management is the process of evolving the management of assets to improve outcomes in the face of climate impacts. It involves an active learning process where new information and feedback is incorporated into resilience efforts. Tracking resilience projects (Section 6.4.1) and the use of resilience metrics and indicators (Section 6.4.2) support adaptive management through continued monitoring and refining transportation decisions accordingly.

Ongoing maintenance of transportation assets and new projects can be informed by the lessons learned through implementing resilience strategies elsewhere in the transportation system. Decision-makers can adapt methods of transportation system management based on the findings of implemented projects (e.g., benefits achieved or challenges that arose), improved technical feasibility, changing agency capacity, or changing climate conditions. Adaptive management ensures that transportation decisions and maintenance of assets reflect the most updated information available and responds to changing climate, community, or agency priorities.

6.5 Best Practices for Implementation

Throughout the implementation process, several key concepts or steps may be considered.

- **Identify a champion for the effort.** MDOT may consider assigning a person or group of people, such as a member of the Internal Advisory Committee, to steward the implementation of this plan. Assigning a specific person or group to this task has the potential to help ensure the implementation process is thoughtful, deliberate, and successful.
- **Develop an equitable approach.** Identify best practices to put the experiences of disadvantaged communities at the center of the implementation process. Resilience improvement strategies should be implemented in alignment with the Justice40 Initiative, which specifies that eligible

agencies, such as MDOT, must work toward the goal of having 40 percent of the overall benefits of federal investments flow to disadvantaged communities. As such, MDOT may consider identifying procedures to ensure that funding for improving the resilience of transportation assets result in tangible benefits to disadvantaged communities. These procedures may include identifying at-risk infrastructure located within or near disadvantaged communities and prioritizing projects that mitigate risk in these communities. Procedures may also include targeted public outreach to ensure that the resilience improvement strategies implemented in disadvantaged communities aligns with the outcomes the communities seek. For example, a community may prefer natural solutions such as increased tree planting to address heat. Similarly, a community may prefer maintenance strategies that limit construction impacts such as noise. The following list provides additional recommendations and resources to incorporate equity into implementation.

  - Build future community engagement and implementation on the existing partnerships and feedback received during the NOAA's Climate and Equity Roundtable in Detroit, which focused on urban flooding in Southeast Michigan/Detroit, neighborhood and basement flooding, aging infrastructure, lake levels, and disinvestment in the area. The purpose of the roundtable was to gather feedback from community members. Participants included SEMCOG, University of Michigan, activists and local leaders, and county and city officials.
  - Incorporate the U.S. Department of Transportation's Equity in Transportation resources into project development and implementation procedures.
  - Use the Transportation Equity Toolkit developed by the University of South Florida Center for Urban Transportation Research for guidance on project prioritization.

- **Increase awareness of climate change risks, resilience strategies, priorities, and resources.** This has the potential to increase climate change risk and resilience literacy throughout the state. MDOT may increase understanding and buy-in from both internal and external stakeholders through the development of an outreach and engagement strategy. Appointed public information officers may be responsible for the collaboration with other existing outreach efforts for climate change within the state. The goal of this outreach and engagement would be to advertise to state agency partners, Tribal nations, and local governments that the implementation of resilient transportation projects is a priority. Possible outreach activities may include the following:
  - Present at or host workshops at industry conferences.
  - Present or host trainings at state and regional government workshops or meetings.
  - Participate in Silver Jackets for Michigan and other standing committee meetings.
  - Consider a "roadshow" or press circuit around the state, or in targeted geographies, for what resources are now available, or will be, and allow communities the opportunity to provide feedback.
- **Stay up to date on best available data and reassess risk.** Regularly update the risk assessment to incorporate new climate projections, FEMA floodplain data, state asset data (such as culvert datasets once they are complete), and additional past flood experience locations. Ensure best

available data are used during the implementation stage of a project. Following are additional data recommendations.

- Community-oriented information, such as community-identified critical routes, problem areas, and needs. Work with communities to identify what they see as successful resilience.
- Expanded pavement condition information. Current data set does not include all roads.
- Additional hazard information, such as riverine erosion hazard data.
- Additional critical infrastructure and asset data, such as routes to hospitals, schools, and economic centers.
- Asset elevation information.

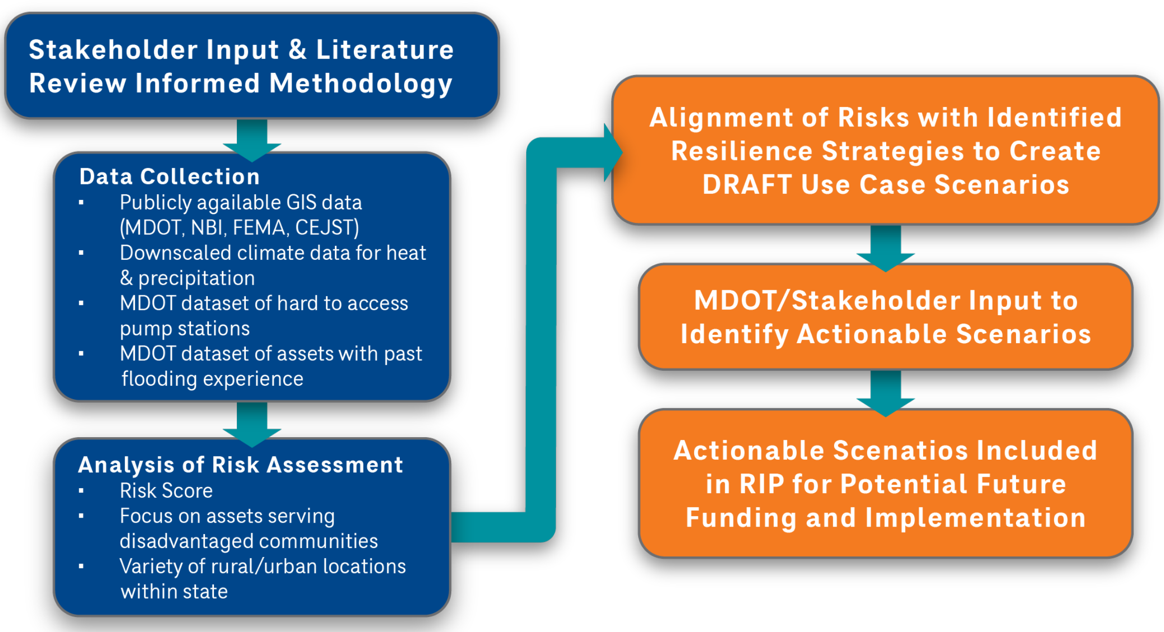
7.0 Use Case Scenarios

7.1 Use Case Scenario Approach

Use case scenarios were developed to represent actionable, implementable potential projects to reduce risk to the four identified hazards for a selection of high-risk assets. Based on the results of the risk assessment, high-risk assets were aligned with the identified resilience strategies described in Section 4.0. During the final Regional Stakeholder Working Group meeting (Section 1.3), MDOT reviewed the high-risk assets and the proposed use case scenario locations with stakeholders. Based on the input received, use case scenarios were refined to remove locations that were not considered priority because site constraints were already under evaluation or were recently upgraded to include resilience improvements. In response to stakeholder feedback, MDOT also added an additional use case scenario to include an example of a roadway with constrained grade because it crosses under a railroad bridge. **Figure 21** presents the use case scenario process.

The scenarios in this section include a detailed description of the surrounding area, an explanation of the factors contributing to the high-risk score, and a proposed resilience strategy or suite of strategies to help reduce risk to the identified asset. Included is information on additional considerations and co-benefits. These scenarios are meant to serve as a connection between the risk assessment and the project implementation phase. However, they do not represent feasibility analyses. Additional studies are required to account for design standards, site constraints, and/or regulatory requirements.

Figure 21. Use Case Scenario Process



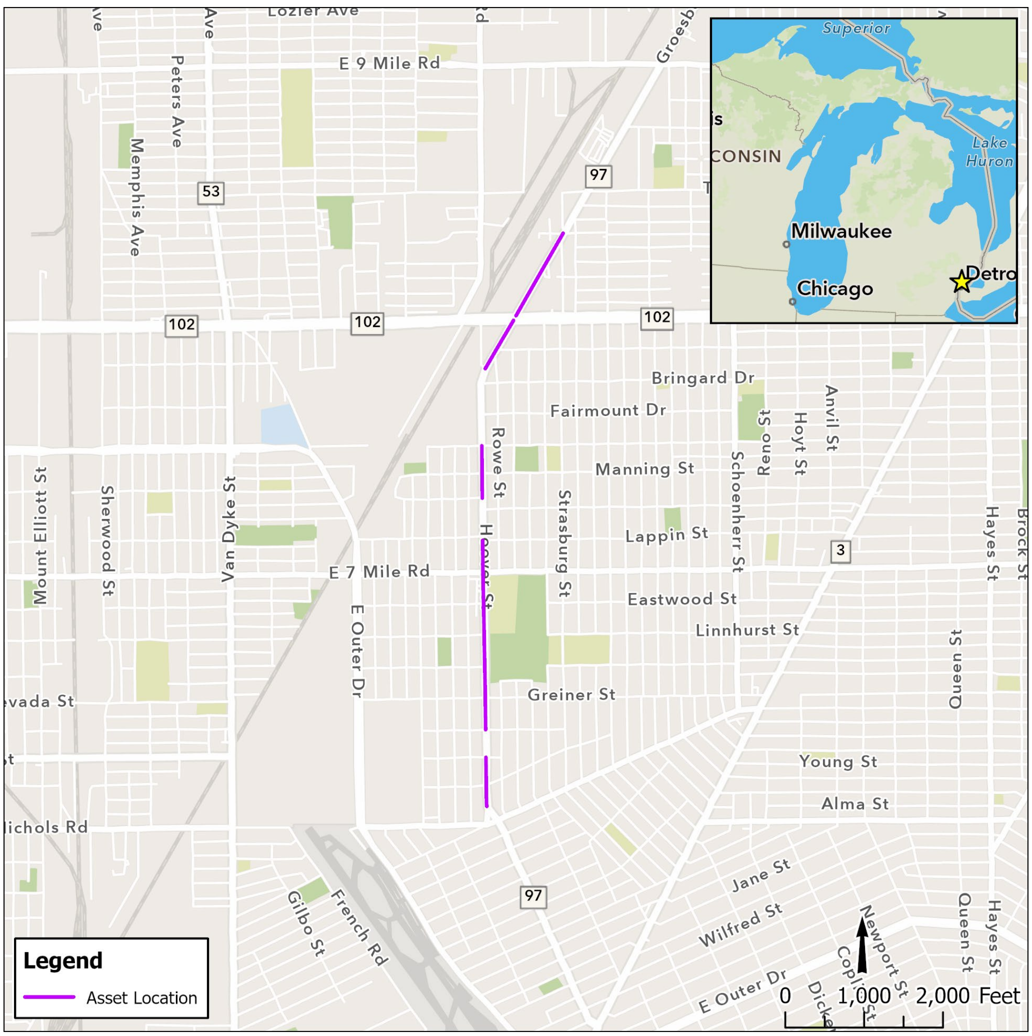
7.2 Roadways

7.2.1 Use Case Scenario Analysis – Heat

7.2.1.1 Location Description

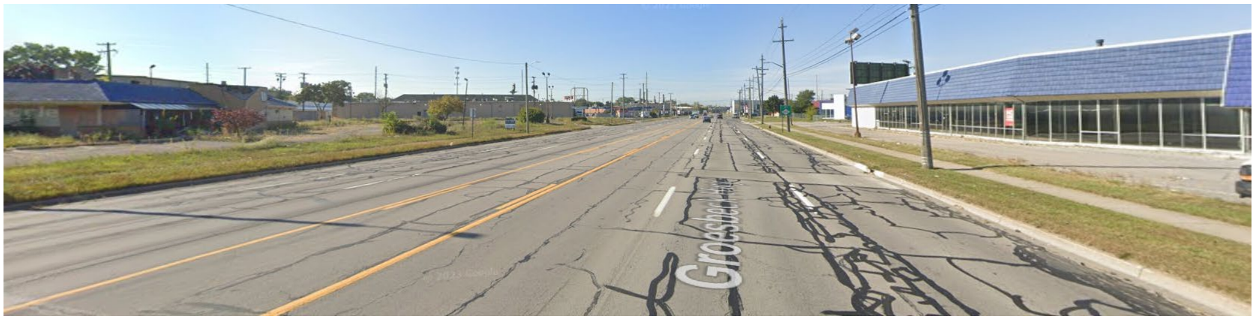
Segments of M-97 (Hoover Street and Groesbeck Highway) in Macomb and Wayne Counties were identified as the highest risk roadway segments to heat hazards. These segments run from the intersection with Prospect Avenue to East McNichols Road (**Figure 22**). These segments are located north of Coleman A. Young International Airport and I-94. According to the Council on Environmental Quality's Climate and Economic Justice Screening Tool (CEJST), all eight of the census tracts along this portion of M-97 are considered disadvantaged communities. For these census tracts, this determination was based on the share of people in households below the federal poverty level, average annual energy costs, higher rates of asthma, lower life expectancy, low income, and unemployment, as well as share of homes likely to have lead paint and other indicators.

Figure 22. High-Risk Road Segments along M-97 in Macomb County and Wayne County



The surrounding land use is a mixture of commercial, industrial, and residential (single-family homes) buildings. These segments of M-97 include six lanes of traffic, reducing to two lanes as it moves south (**Figure 23**). Impervious surface dominates the right-of-way along many of these segments with minimal vegetation. Long stretches of roadway in this area do not have street trees in the right-of-way; grass is present along sidewalks in most areas.

Figure 23. M-97 Google Street View



7.2.1.2 Risk Assessment Results

These segments of M-94 were categorized as high exposure to extreme heat based on a high percentage of impervious surface within the watershed, a projected increase in days with temperatures above 90°F by mid-century, and their location within an idea identified as experiencing higher temperatures than the surrounding areas. These segments were categorized as high sensitivity because of poor pavement condition and pavement material (AC overlay over existing jointed concrete pavement) that is likely more sensitive to heat impacts. This part of M-94 was given a high criticality score in the risk assessment because it is located within disadvantaged communities, has high AADT and truck traffic, is located on the National Highway System, and has a high functional class. **Table 20** provides risk assessment results for these road segments and the factors that contributed to the scores.

Table 20. Risk Assessment Results for M-94 – Extreme Heat

Physical Road Number (PR)	Assessment Factor	Score	Contributing Factors	Determination
803009; 15880008	Exposure	3.5	▪ Impervious surface: 61%–66% ▪ +22 days above 90°F by mid-century ▪ Severe heat area	High
	Sensitivity	4	▪ Poor pavement condition ▪ Pavement material sensitive to heat	High
	Criticality	3.85	▪ Located within a disadvantaged community ▪ AADT: 9,109–16,768 ▪ AADT truck traffic: 486–949 ▪ Located on National Highway System ▪ Functional class: Other principal arterials	High
	Risk	3.68		High

7.2.1.3 Resilience Strategy

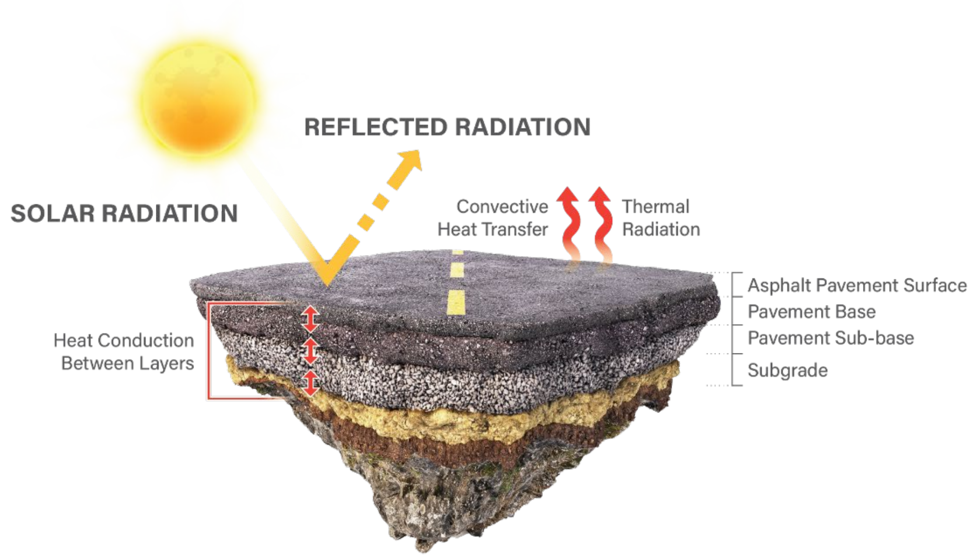
The recommended resilience strategy for M-94 (Hoover Street and Groesbeck Highway) is the combination of green infrastructure/nature-based solutions and structural heat resilience measures to improvement pavement performance.

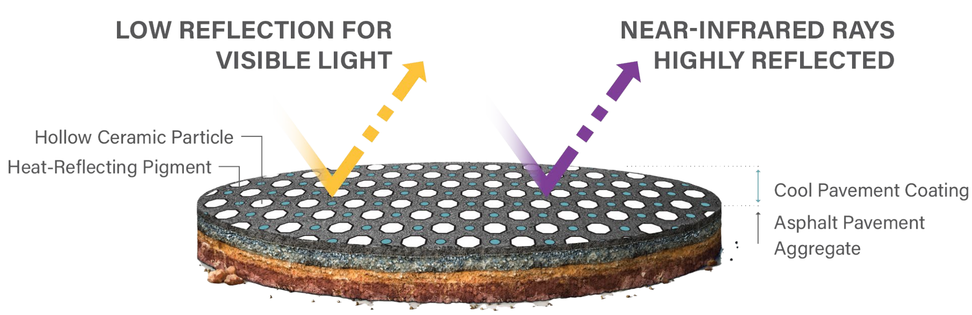
Planting trees in the right-of-way provides shade to infrastructure, thereby reducing the absorption of heat. It has been shown to result in better pavement performance during extreme heat (**Figure 24**).[lvi] The cooling effect of planting trees reduces the daily heating and cooling, and associated expansion/contraction, of asphalt, leading to a longer lifespan of pavement.[lvii] Further, planting trees in the right-of-way can provide shade for people walking, biking, or using transit spots (benefits beyond infrastructure resilience).

Figure 24. Example of Urban Street Trees[lviii]

When road surfaces absorb heat, the heat transfers to sublayers of the pavement and can put stress on the base layers resulting in deterioration such as buckling, softening asphalt, and rutting, which leads to cracking and potholing.[lix] Using heat-resistant materials, including asphalt mixes with higher melting points, glazing materials, reflective sealcoats, and lighter colored road surfaces, reduces the amount of heat that a roadway absorbs.[lx] In addition, increasing the thermal expansion capacity of this infrastructure, such as through incorporating expansion joints or fiber-reinforced concrete, improves the ability of the road to expand and contract with changing temperatures, thereby reducing the occurrences of buckling, cracking, and potholing. Similarly, incorporating the use of geotextiles reduces heat-induced deformations of roadways. **Figure 25** depicts how heat is transferred through traditional asphalt pavement compared to pavement with a reflective topcoat.

Figure 25. Impact of Heat on Traditional Asphalt Compared to with Reflective Topcoat

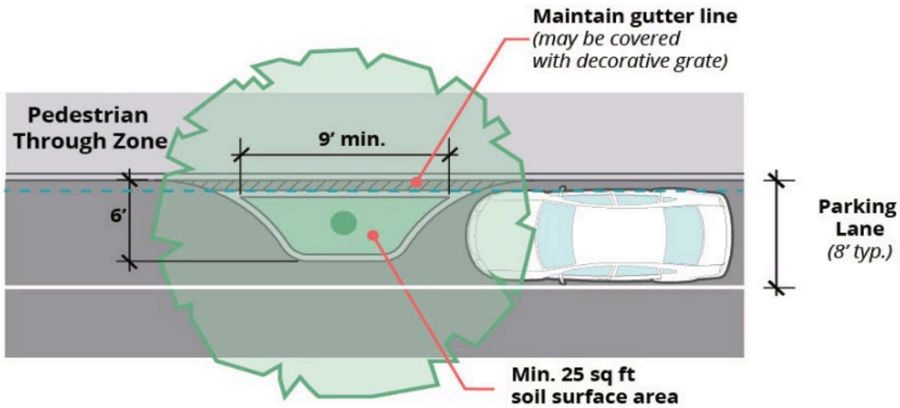




7.2.1.4 Resilience Strategy Considerations

Trees require adequate space for root growth and require consistent maintenance when first planted, such as adequate watering and staking. The appropriate species of trees should be considered to ensure that at maturity, the size of the tree is suited to its surrounding and minimizes the need for pruning (e.g., consider height of mature tree compared to height of overhead power lines). The placement of trees near intersections should ensure that adequate sight lanes are available to drivers. Best management practices and design manual standards should be used or developed to facilitate implementation. **Figure 26** depicts an example of spacing considerations for planting street trees.

Figure 26. Example of Street Tree Planting Design[lxi]



There are various heat-resistant materials and methods of implementing such materials on roadways. As such, there are variations in the applicability, level of effort, cost, and effectiveness. AC mixtures can be used wherever pavement is used but require the replacement of existing materials. Glazing and reflecting sealcoats can be placed on top of existing materials and may be more cost-effective, require less effort and time to implement, and minimize the need for road closures, lane closures, or detours during implementation. However, reflective sealcoats may also result in glare, which can pose safety concerns.

Conversely, if a segment of roadway is considered in poor condition and rebuild efforts are currently planned, replacing the pavement material may be more beneficial than using a glazing or topcoat. MDOT can incorporate heat-resistant upgrades to pavement as part of their planned maintenance and/or scheduled repairs of this segment of interstate. Similarly, heat-resistant upgrades as part of maintenance and scheduled repairs could become a standard practice for all road segments with similar risk to extreme heat.

7.2.1.5 Description of Co-Benefits

Incorporating green infrastructure/natural resources, and in particular planting urban trees, has multiple co-benefits. In addition to reducing the impact of heat on pavement and roadways, urban tree planting reduces the overall ambient temperature and provides shade for people walking and biking.[lxii] Planting trees can improve air quality because the trees remove pollutants such as ozone, sulfur dioxide, particulate matter, nitrogen dioxide, and carbon monoxide from the air.[lxiii] Similarly, trees can benefit water quality by filtering pollutants through their root systems. Trees capture and store rainfall, thereby reducing the amount of pollutant runoff carried into wastewater systems and local waterways during rain events. Trees and planting can also provide visual and aesthetic benefits to communities by increasing the presence of natural features in heavily built-out environments. Tree planting has been associated with increased property values and profits for businesses.[lxiv] Planting trees along urban roadways reduces driver stress, calms traffic, and reduce the number of crashes.[lxv]

Co-benefits associated with the use of heat-resistant materials center around the increased durability of infrastructure. Improving durability can lengthen the lifespan of infrastructure and prolong the need for reconstruction and associated impacts such as noise and reductions in air quality from construction equipment emissions. Increasing durability reduces the occurrence of pavement deterioration and the potential for road detours or closures and associated reduction of access to facilities or disruptions in the supply chain. Reducing pavement deterioration also improves the safety of the roadway, thereby reducing the potential for accidents and/or loss of life.[lxvi]

7.2.2 Use Case Scenario Analysis – Coastal Erosion

7.2.2.1 Location Description

The segments identified for this use case scenario analysis are along US-23 (Lake Street/Bay Street) from 9th Avenue to 1st Street (**Figure 27**), and from Oak Street to just north of Pine Street (**Figure 28**). These segments are located in Tawas City on the coast of Lake Huron. On West Lake Street, the surrounding land use is primarily residential to the south with increasing commercial uses to the north. Two parks provide access to the shoreline (Gateway Park at the southern end, Tawas City Shoreline Park at the northern end). This segment of roadway includes two lanes of traffic, one lane in each direction and a center turn lane. The shoreline of this segment contains mixed features, including sandy beaches, rock revetments, breakwaters, and bulkheads. According to CEJST, the area is considered a disadvantaged community based on higher rates of heart disease, low income, share of homes with underground storage tanks, and releases.

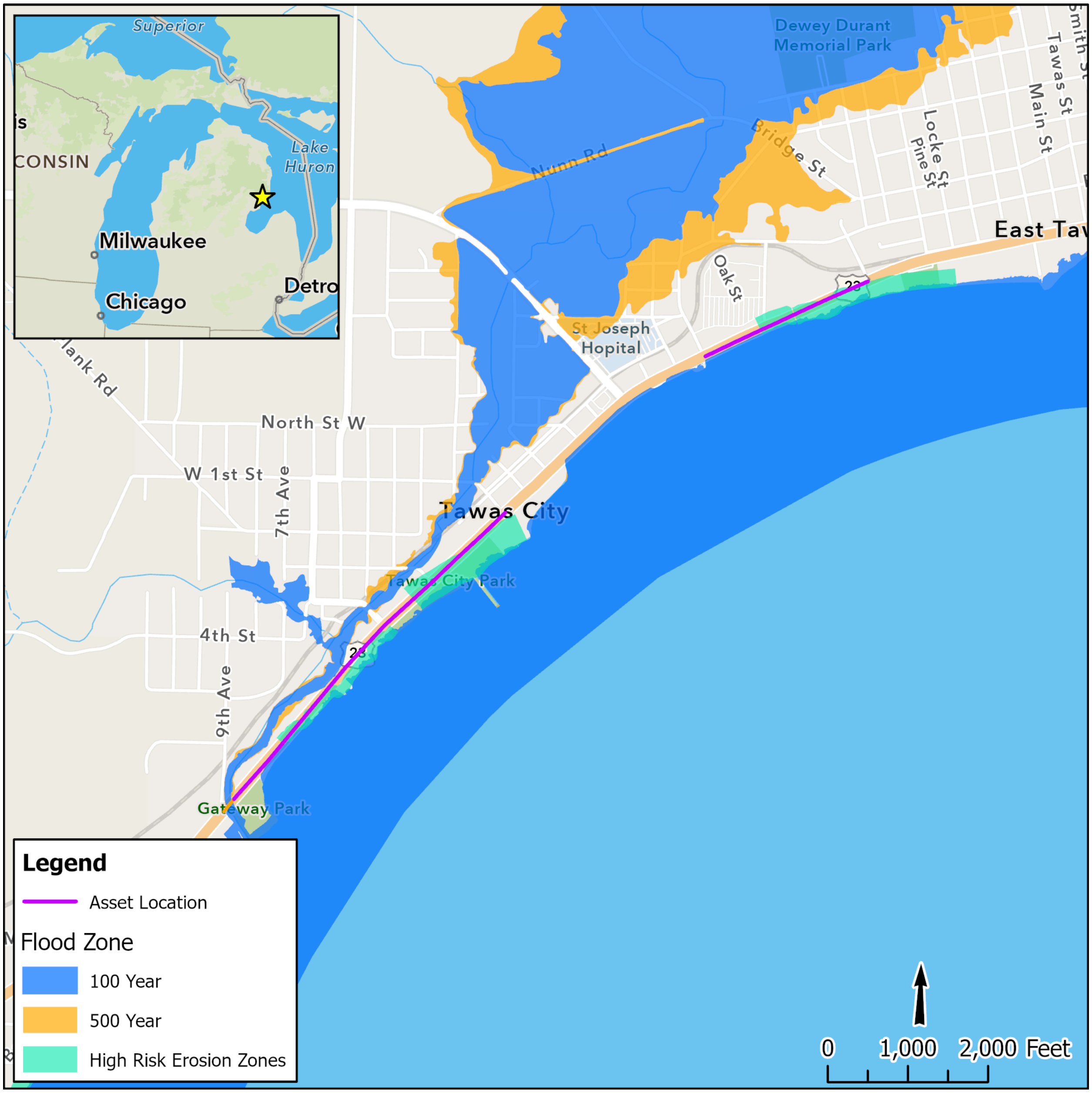
On East Lake Street, the surrounding land use is primarily commercial with a pocket of residences at the northern end. This segment of roadway includes four lanes of traffic, two in each direction and a center turn lane. The southern end of this segment contains a rock revetment. The northern end does not contain shoreline protection features.

Figure 27. West Lake Street from 9th Avenue to 1st Street

Figure 28. East Lake Street from Oak Street to just North of Pine Street

These roadway segments are located within Michigan's high-risk erosion zones and within close proximity to the 100-year floodplains of both Lake Huron and the Tawas River (**Figure 29**).

Figure 29. Location of the Roadway Segments at Risk to Coastal Erosion in Tawas City



7.2.2.2 Risk Assessment Results

These roadway segments scored high risk to coastal erosion based on their location within the High-Risk Erosion Zones. Their high criticality scores were based on location within a disadvantaged community, high AADT and truck traffic values, location along the National Highway System, and a high functional class. The risk assessment for coastal erosion did not include sensitivity indicators. **Table 21** provides additional information on the risk assessment results for these road segments.

Table 21. Risk Assessment Results for West Lake Street and East Lake Street – Coastal Erosion

Physical Road Number (PR)	Assessment Factor	Score	Contributing Factors	Determination
1251607	Exposure	4	▪ Located within High-Risk Erosion Zone	High
	Sensitivity	N/A	N/A	N/A
	Criticality	3.7	▪ Located within a disadvantaged community ▪ AADT: 8,265–12,912 ▪ AADT truck traffic: 168 ▪ Located on National Highway System ▪ Functional class: Other principal arterials	High
	Risk	3.93		High

7.2.2.3 Resilience Strategy

The resilience strategy for these segments of roadway is to incorporate the use of green infrastructure/natural resources. Living shorelines protect and stabilize the shoreline using natural materials such as plants, sand, and rock (**Figure 30**). Unlike hard structures, such as a concrete sea wall, living shorelines can grow over time and are more resilient against storms and fluctuating lake levels.[lxvii] Combining natural and hardscape design elements can provide similar co-benefits as natural shorelines but are more feasible in areas where there is little space to implement natural approaches alone. Combining natural and hardscape elements can provide maximum protection by capitalizing on the strengths of both approaches. For example, hardscape elements can protect natural features as they become established.

Figure 30. Living Shoreline at Rogue Power Plant, Michigan (Left–Before, Right–After)[lxviii]

7.2.2.4 Resilience Strategy Considerations

No single design for living shorelines and/or combination of natural and hardscape designs are a one-size-fits-all solution. The design must consider contextual factors such as the energy of waves hitting the shoreline, the slope required to adequately mitigate erosion, and the ability to perform maintenance.[lxix]

7.2.2.5 Description of Co-Benefits

Incorporating green infrastructure/natural resources using living shorelines and combining natural and hardscape elements provide co-benefits such as improving water quality, promoting recreation, creating green space, as well as reducing the risk of substantial damage and loss. Natural features improve water quality by filtering pollutants and trapping sediment with their root systems. Living shorelines and combined features maintain recreational access to the shoreline. Creating green space also maintains the natural feel of the shoreline and avoids an unnecessary increase in built structures. Green infrastructure along shorelines provides protection from erosion by reducing scour from waves and it can adapt to changing lake levels over time. Protecting against erosion mitigates the risk of deteriorating infrastructure and destabilizing slopes.

7.2.3 Use Case Scenario Analysis – Stormwater Flooding

7.2.3.1 Location Description

The roadway segments identified for this use case scenario are located in Dearborn, Michigan, along I-94 as it crosses beneath the Penn Central Railroad near the ramp to Rotunda Drive (**Figure 31**). According to CEJEST, these roadways are located within a disadvantaged community. The census tract is considered disadvantaged based on the average annual energy costs relative to household income, the share of people in households below the federal poverty level, higher rates of asthma, lack of green space, share of homes likely to have lead paint, traffic proximity and volume, unemployment, and other indicators.

Figure 31. High-Risk Road Segments along I-94 in Dearborn

The surrounding land use is a mixture of commercial, industrial, and residential. These segments of I-94 include six lanes of traffic and are at a lower elevation than the surrounding areas with grassy slopes in the right-of-way on both sides. The roadway reduces grade to pass below the railroad track overpass.

Figure 32. I-94 Google Street View

7.2.3.2 Risk Assessment Results

These segments of I-94 were categorized as high exposure to stormwater flooding based on a high percentage of impervious surface within the watershed, a projected increase in days with precipitation greater than 3 inches (days/decade) by mid-century, and past issues with stormwater flooding. The segments were categorized as medium sensitivity because of fair pavement condition. This portion of I-94 was given a high criticality score in the risk assessment because it is located within a disadvantaged community, has high AADT and truck traffic, is located on the National Highway System, and has a high functional class. **Table 22** provides the risk assessment results for these road segments and the factors that contributed to the scores.

Table 22. Risk Assessment Results for I-94 – Stormwater Flooding

Physical Road Number (PR)	Assessment Factor	Score	Contributing Factors	Determination
1576405; 1588802	Exposure	4	▪ Past flood experience ▪ Impervious surface: 67% ▪ +3.2 days with precipitation > 3 inches by mid-century (days/decade)	High
	Sensitivity	2.5	▪ Fair pavement condition	Medium
	Criticality	3.1–4	▪ Located within a disadvantaged community ▪ AADT: 90,553 ▪ AADT truck traffic: 6,981 ▪ Located on National Highway System ▪ Functional class: Interstate	High
	Risk	3.49–3.72		High

7.2.3.3 Resilience Strategy

The recommended resilience strategy for this portion of I-94 is to assess the area for possible stormwater management infrastructure improvements. Potential actions could include assessing existing stormwater inlets for debris or blockages and conducting maintenance to improve flow. Additionally, MDOT could perform a wet weather inspections of the section to identify the source of ponding and, consequently, flooding. The inspection could assess stormwater flow paths, inlet performance, and whether drainage from the railroad track is contributing to the stormwater flooding beneath the bridge. Depending on site feasibility, additional actions could include improving stormwater capture and conveyance (e.g., increasing the size of the existing inlets, adding additional inlets, and/or adding additional storage alongside the interstate). If feasible, part of the grassy areas on either side of the interstate could be removed for additional storage.

7.2.3.4 Resilience Strategy Considerations

Climate projections should be considered if increasing the size of existing inlets, adding additional inlets, or increasing storage alongside the roadway segments. Right-of-way size will be a limiting factor for any potential actions. Resilience strategy implementation could also consider the nearby pump station located on the west side of I-94 just north of the railroad bridge. The pump station is currently funded for improvements. These improvements should consider increased rainfall because of climate change and ensure sufficient capacity to help reduce the stormwater flooding below the bridge. When conducting the wet weather assessment, MDOT could determine whether the flooding issue is related to pump station capacity, stormwater conveyance, or a combination.

7.2.3.5 Description of Co-Benefits

These resilience measures have the added benefits of reducing delays in travel times and avoiding costs related to travel disruptions. Reducing flood risk can improve community safety and prevent potential injuries or property damage. Increased resilience would also reduce supply chain disruptions and negative impacts to the surrounding businesses and communities.

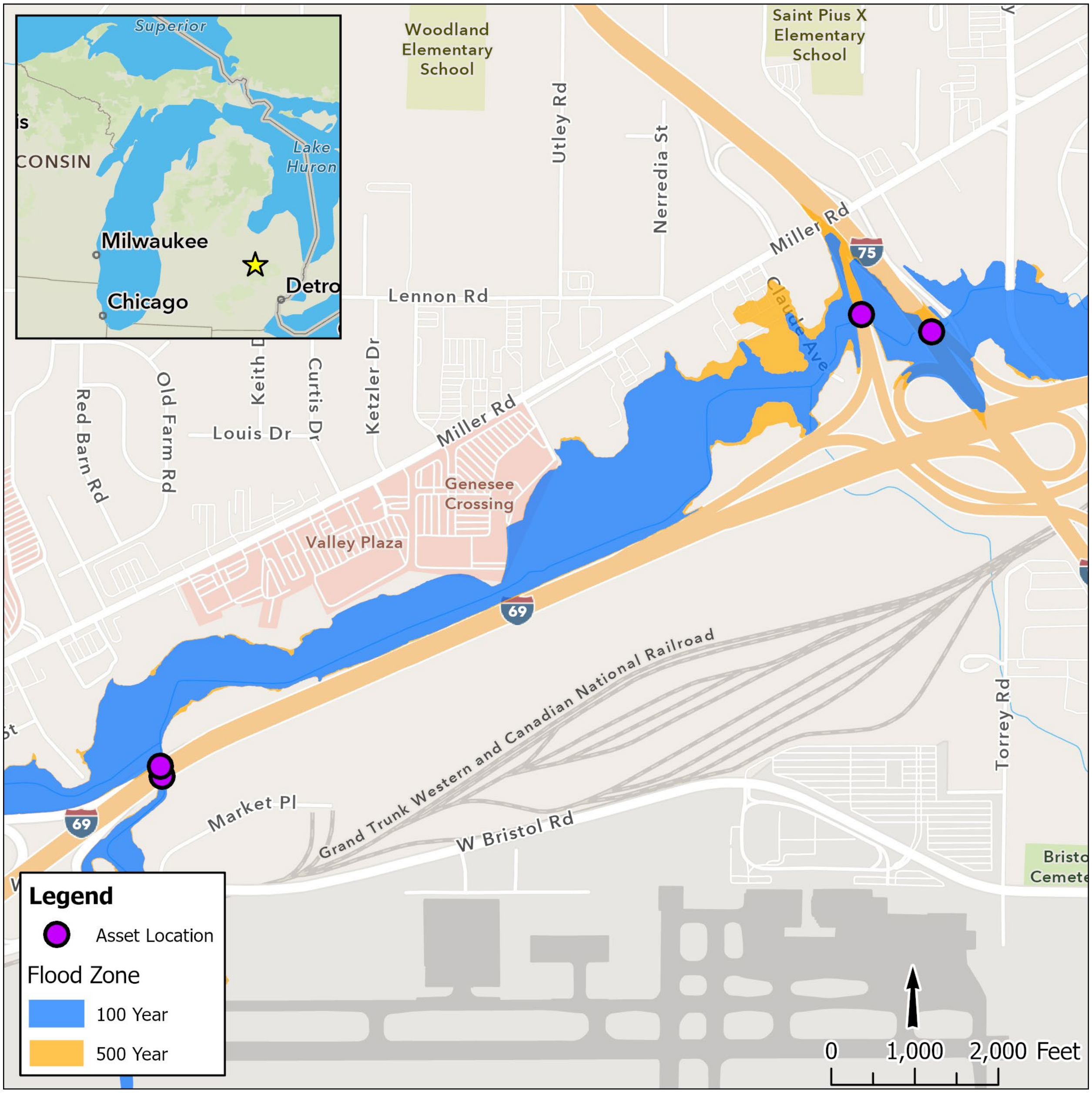
7.3 Bridges

7.3.1 Use Case Scenario Analysis – Riverine Flooding

7.3.1.1 Location Description

The four highest ranking bridges for riverine flood risk are all located within Genese County, between the City of Swartz Creek and the City of Flint. Two bridges are located on I-69 as it crosses Swartz Creek to the southwest of the I-75/I-69 interchange. One bridge crosses Swartz Creek on the off-ramp from I-75 southbound toward I-69. The fourth bridge is located on I-75 before it crosses I-69, as shown in **Figure 33**.

Figure 33. Locations of the Four Bridges Identified as the Highest Risk to Riverine Flooding



All four bridges are located within the 100-year floodplain of Swartz Creek. Three of the four bridges were constructed more than 60 years ago, and all four bridges were designated as scour critical with foundations that are considered unstable because of scour conditions. All four bridges are located on highly trafficked interstates. According to CEJST, these bridges are located within a census tract considered to be a disadvantaged community. This is based on a high number of unemployed people and a high percentage of people who have not graduated high school.

Based on stakeholder feedback and MDOT data on past flood events, in May 2011, flooding from Swartz Creek caused increased scour issues and undermined the pier footings of the I-69 bridge of the creek (**Figure 34**).

Figure 34. Google Earth 3D Screen Capture of Bridges ID 25125042000B023 and 25125042000B024 along I-69[lxx]

The following year, flooding in the area resulted in a shutdown of the I-75/I-69 interchange (**Figure 35**) and caused significant scour holes at I-75 over Swartz Creek (**Figure 36**).

Figure 35. Google Earth Screen Capture of Bridge ID 25125042000B050 on the Off-Ramp from I-75 to I-69[lxxi]

Figure 36. Google Earth Screen Capture of Bridge ID25125031000B030 on I-75[lxxii]

7.3.1.2 Risk Assessment Results

These bridges received high riverine/coastal flooding exposure scores based on past flood experience, projected increase in days with precipitation greater than 3 inches by mid-century, and proximity to the 100-year floodplain. They scored high sensitivity scores based on high scour criticality and the older age of the structures. The bridges were given high criticality scores in the risk assessment because they are located within a disadvantaged community, have high AADT and truck traffic, are located on the National Highway System, and have a high functional class. **Table 22** provides the risk assessment results for these road segments and the factors that contributed to the scores.

Table 23. Risk Assessment Results for Four-High Risk bridges on I-75 and I-69

Bridge ID	Location Description	Assessment Factor	Score	Contributing Factors	Determinations
25125042000B023	I-69 Eastbound	Exposure	3.85	▪ Past flooding experience ▪ +1.6 days with precipitation >3 inches by mid-century (days/decade) ▪ Located within the 100-year floodplain	High
		Sensitivity	3.75	▪ Age (built in 1968)	High

Bridge ID	Location Description	Assessment Factor	Score	Contributing Factors	Determinations
				▪ Scour criticality: Bridge is scour critical; bridge foundations were determined to be unstable for assessed or calculated scour conditions.	
		Criticality	4	▪ Located within a disadvantaged community ▪ AADT: 25,506 ▪ AADT truck traffic: 2,806 ▪ Located on National Highway System ▪ Functional class: Interstate	High
		Risk	3.87		High
25125042000B024	I-69 Westbound	Exposure	3.85	▪ Past flooding experience ▪ +1.6 days with precipitation >3 inches by mid-century (days/decade) ▪ Located within the 100-year floodplain	High
		Sensitivity	3.75	▪ Age (built in 1968) ▪ Scour criticality: Bridge is scour critical; bridge foundations were determined to be unstable for assessed or calculated scour conditions.	High
		Criticality	4	▪ Located within a disadvantaged community ▪ AADT: 25,506 ▪ AADT Truck Traffic: 2,806 ▪ Located on National Highway System ▪ Functional class: Interstate	High
		Risk	3.87		High
25125042000B050	I-75 Ramps A and C	Exposure	3.85	▪ Past flooding experience ▪ +1.6 days with precipitation >3 inches by mid-century (days/decade) ▪ Located within the 100-year floodplain	High

Bridge ID	Location Description	Assessment Factor	Score	Contributing Factors	Determinations
		Sensitivity	3.75	▪ Age (built in 1969) ▪ Scour criticality: Bridge is scour critical; bridge foundations were determined to be unstable for assessed or calculated scour conditions.	High
		Criticality	4	▪ Located within a disadvantaged community ▪ AADT: 11,275 ▪ AADT Truck Traffic: 1,015 ▪ Located on National Highway System ▪ Functional class: Interstate	High
		Risk	3.87		High
25125031000B030	I-75	Exposure	3.85	▪ Past flooding experience ▪ +1.6 days with precipitation >3 inches by mid-century (days/decade) ▪ Located within the 100-year floodplain	High
		Sensitivity	3.55	▪ Scour criticality: Bridge is scour critical; bridge foundations were determined to be unstable for assessed or calculated scour conditions.	High
		Criticality	4	▪ Located within a disadvantaged community ▪ AADT: 66,912 ▪ AADT Truck Traffic: 4,684 ▪ Located on National Highway System ▪ Functional class: Interstate	High
		Risk	3.83		High

7.3.1.3 Resilience Strategy

To improve the resilience of this area, a suite of resilience strategies could be implemented. Several issues are contributing to the flooding at this site, including confined waterway openings below bridges and the low grade south of the interchange to avoid the railroad crossing. Structural flood resilience measures could be used, such as raising the bridge deck elevations and/or lengthening of the bridges to expand the waterway opening (**Figure 37**). This would allow more water to pass under each bridge without flooding into the roadway. Ensuring that the creek was free of log jams and other debris would help prevent additional flooding during high flows. Although riverine flooding primarily causes this flood risk, improving the road drainage systems near the railroad would help prevent floodwaters from collecting in the lower grade parts of the interchange. Reinforcing exposed areas of the bridge by increasing protection of embankments from scouring could allow for “safe” overtopping over the infrastructure.

Figure 37. Bridge Deck in Houston, Texas[lxxiii]

7.3.1.1 Resilience Strategy Considerations

Implementing resilience measures to this area with a focus on the system as a whole will help ensure that the measures implemented to one bridge does not increase flooding issues to another. Additionally, to ensure the movement of traffic through this area, all assets need to be fully functional. Implementation of this strategy would cause significant disruptions to the area, such as road closures and increases in traffic during construction. The proposed alterations to the bridge structures should consider protection from scour.

7.3.1.2 Description of Co-Benefits

This suite of resilience measures has the added co-benefits of reducing the loss of property and damage due to flooding events to the surrounding areas. This avoids potential costs associated with repairing property and disruptions to normal operations. Reducing flood risk to the area can improve community safety and prevent injuries or loss of life during flooding events. The increased resilience of this area would reduce transit disruptions, supply chain interruptions, and negative impacts to surrounding businesses and communities.

7.4 Programmatic and Other Initiatives

This section identifies programmatic initiatives that MDOT can take to improve the resilience of the transportation system. Programmatic initiatives can be used across transportation assets to inform site-specific actions.

7.4.1 Use Advanced Monitoring and Modeling Tools

Climate monitoring systems, such as weather stations and sensors embedded into roads and bridges, can provide valuable data for early warnings of climate hazard events. These data also could be used to optimize decision-making during hazardous situations. For example, such data can be used to identify the best alternative routes during climate hazard events or inform emergency response teams.

Advanced modeling tools can be used to identify the future risk to transportation infrastructures, such as changes in rainfall, precipitation patterns, or freeze–thaw cycles. Modeling future risk could inform the design of transportation assets to withstand future changes in climate hazards. Modeling could be used similarly during the reconstruction or redesign of high-risk assets.

7.4.2 Regular Maintenance of Assets

Regular maintenance of transportation assets is an important initiative to improve the resilience of the transportation system, maintain safe and effective transportation throughout Michigan, and ensure continued access to homes, businesses, and community facilities. Exposure to climate hazards can shorten the lifespan of infrastructure and exacerbate the natural degradation of assets over time. Regular maintenance can reduce the impact of climate hazards by repairing degraded infrastructure or upgrading infrastructure to better withstand climate condition, thereby minimizing the deterioration associated with climate events. Risk assessment map data (Section 3.6.3) could be used to prioritize maintenance of assets at high risk and/or to ensure that maintenance adequately addresses the vulnerability of a particular asset.

7.4.3 Consider Relocation and Retreat Plans

Moving infrastructure away from environmental stressors like floodplains and shorelines reduces, and in some cases can eliminate, the risk of assets being damaged or destroyed as a result of climate events. Relocation and retreat of infrastructure creates a buffer between transportation assets and vulnerable areas. For example, moving roadways outside of the floodplain reduces the likelihood of roadways flooding during heavy rain events; can eliminate the need for flood-related design standards and repairs (e.g., elevation above the floodplain). Similarly, constructing assets further inland reduces the likelihood of erosion creating unstable ground conditions that crack and deteriorate roadways, as well as the loss of assets to receding shorelines. Relocation and retreat of infrastructure is a long-term initiative that requires robust coordination across multiple agencies and jurisdictions and careful consideration of the needs and input of the public. Developing coordinated outreach efforts and relocation/retreat management plans can ensure that access to homes, businesses, and community facilities is maintained and/or improved as transportation infrastructure is shifted away from hazard-prone areas.

Appendix A: Risk Assessment Methodology

A.1 Exposure

To calculate exposure for riverine and coastal flooding for all assets, the risk assessment used a geospatial analysis of three indicators: past flood experience, FEMA flood zone, and the projected change in days with precipitation greater than 3 inches. **Table 24** summarizes these indicators, the values used to assign the score, and the weight of the indicator in the overall exposure score.

Table 24. Exposure Scoring Approach for Riverine and Coastal Flooding for All Assets

Indicator	Indicator Value	Score	Weight
Past flood experience[lxxiv]	Not included in data set provided by MDOT	1	50%
	Included in data set provided by MDOT	4	
FEMA Flood Zone[lxxv]	No digital data available	1	35%
	Asset located more than 200 feet outside of the 500-year flood zone	1	
	Asset located outside of flood zone but within 200 feet of the 500-year flood zone	2	
	Within 500-year flood zone	3	
	Within 100-year flood zone	4	
Change in Days with Precipitation >3 inches[lxxvi]	0 to 25th percentile	1	15%
	25th to 50th percentile	2	
	50th to 75th percentile	3	
	75th to 100th percentile	4	

To calculate exposure for stormwater flooding for all assets, the risk assessment used a geospatial analysis of three indicators: past flood experience, impervious surface, and the projected change in days with precipitation greater than 3 inches. **Table 25** summarizes these indicators, the values used to assign the score, and the weight of the indicator in the overall exposure score.

Table 25. Exposure Scoring Approach for Stormwater Flooding for Roadways, Culverts, and Pump Stations

Indicator	Indicator Value	Score	Weight
Past flood experience[lxxvii]	Not included in data set provided by MDOT	1	70%
	Included in data set provided by MDOT	4	
Impervious surface percentage within watershed[lxxviii]	Determined based on natural breaks	1	15%
		2	
		3	
		4	
Change in Days with Precipitation >3 inches[lxxix]	0 to 25th percentile	1	15%
	25th to 50th percentile	2	

Indicator	Indicator Value	Score	Weight
	50th to 75th percentile	3	
	75th to 100th percentile	4	

To calculate exposure for coastal erosion for all assets, the risk assessment used a geospatial analysis of the asset's location relative to the High-Risk Erosion Zone. **Table 26** summarizes this indicator, the values used to assign the score, and the weight of the indicator in the overall exposure score.

Table 26. Exposure Scoring Approach for Coastal Erosion for All Assets

Indicator	Indicator Value	Score	Weight
Location relative to high-risk erosion zones[lxxx]	Not located within a High-Risk Erosion Zone	1	100%
	Located within a High-Risk Erosion Zone	4	

To calculate exposure for heat for roadways and bridges, the risk assessment used a geospatial analysis of three indicators: impervious surface, projected change in days above 90°F, and relative heat severity. **Table 27** summarizes these indicators, the values used to assign the score, and the weight of the indicator in the overall exposure score.

Table 27. Exposure Scoring Approach for Heat for Roadways and Bridges

Indicator	Indicator Value	Score	Weight
Impervious surface percentage within watershed[lxxxi]	Determined based on natural breaks	1	25%
		2	
		3	
		4	
Change in Days Above 90°F[lxxxii]	0 to 25th percentile	1	25%
	25th to 50th percentile	2	
	50th to 75th percentile	3	
	75th to 100th percentile	4	
Heat Severity[lxxxiii]	Not included in data set (100)	1	50%
	Mild heat area (1, 2)	2	
	Moderate heat area (3)	3	
	Severe heat area (4, 5)	4	

A.2 Sensitivity

To calculate sensitivity for riverine/coastal flooding for roadways, the risk assessment used pavement condition as the sole indicator. **Table 28** summarizes the values used to assign the score and the weight of the indicator in the overall exposure score.

Table 28. Sensitivity Scoring Approach for Riverine/Coastal and Stormwater Flooding for Roadways

Indicator	Indicator Value	Score	Weight
Pavement Condition[lxxxiv]	Good or None	1	100%
	Fair	2.5	
	Poor	4	

To calculate sensitivity for heat for roadways, the risk assessment used a geospatial analysis of two indicators: pavement condition and pavement material. **Table 29** summarizes these indicators, the values used to assign the score, and the weight of the indicator in the overall exposure score.

Table 29. Sensitivity Scoring Approach for Heat for Roadways

Indicator	Indicator Value	Score	Weight
Pavement Condition[lxxxv]	Good or None	1	75%
	Fair	2.5	
	Poor	4	
Pavement Material [lxxxvi]	1. Unpaved (a. dirt, b. gravel, c. other) or None	1	25%
	3. Jointed Plane Concrete Pavement (JPCP)	2	
	4. Jointed Reinforced Concrete Pavement (JRCP)	3	
	5. Continuously Reinforced Concrete Pavement (CRCP)	3	
	9. Unbonded Jointed Concrete Overlay on Portland Cement Concrete (PCC) Pavements	3	
	10. Unbonded CRCP Overlay on PCC Pavements	3	
	11. Bonded PCC Overlays on PCC Pavements	3	
	2. Bituminous	4	
	6. Asphalt-Concrete (AC) Overlay over Existing AC Pavement	4	
	7. AC Overlay over Existing Jointed Concrete Pavement	4	
	8. AC (Bi Overlay over Existing CRCP)	4	

To calculate sensitivity for flooding for bridges, the risk assessment used a geospatial analysis of three indicators: bridge condition, bridge age, and scour criticality. **Table 30** summarizes these indicators, the values used to assign the score, and the weight of the indicator in the overall exposure score.

Table 30. Sensitivity Scoring Approach for Riverine Flooding for Bridges

Indicator	Indicator Value	Score	Weight
Bridge Condition[lxxxvii]	Good (7–9), N or None	1	10%
	Fair (5–6)	2.5	
	Poor (0–4)	4	
Bridge Age[lxxxviii]	0–20 years	1	10%
	21–40 years	2	
	41–60 years	3	
	>60 years	4	
Scour Criticality[lxxxix]	9: Foundations are well above flood water elevations.	1	80%
	8: Countermeasures are installed to correct scour critical condition.	2	
	7: Countermeasures are installed to correct scour critical condition.	2	
	5: A detailed scour study has found structure stable.	2	

Indicator	Indicator Value	Score	Weight
	4: Stable structure. Action is required to protect exposed foundation.	3	
	3: Bridge is scour critical; bridge foundations are determined to be unstable for assessed or calculated scour conditions.	4	
	2: Scour critical; extensive scour is found at foundation.	4	

To calculate sensitivity for heat for bridges, the risk assessment used a geospatial analysis of two indicators: bridge condition and bridge age. **Table 31** summarizes these indicators, the values used to assign the score, and the weight of the indicator in the overall exposure score.

Table 31. Sensitivity Scoring Approach for Heat for Bridges

Indicator	Indicator Value	Score	Weight
Bridge Condition[xc]	Good (7–9), N or None	1	70%
	Fair (5–6)	2.5	
	Poor (0–4)	4	
Bridge Age[xci]	<20 years	1	30%
	20–40 years	2	
	40–60 years	3	
	>60 years	4	

To calculate sensitivity for flooding for pump stations, the risk assessment used a geospatial analysis of three indicators: access issues, pump station age, and pump station condition. **Table 32** summarizes these indicators, the values used to assign the score, and the weight of the indicator in the overall exposure score.

Table 32. Sensitivity Scoring Approach for Flooding for Pump Stations

Indicator	Indicator Value	Score	Weight
Access Issues[xcii]	Not included in list of difficult to access pump stations	1	40%
	Included in list of difficult to access pump stations	4	
Pump Station Age[xciii]	<20 years	1	30%
	20–40 years	2	
	40–60 years	3	
	Greater than or equal to 60 years	4	
Pump Station Condition[xciv]	Good	1	30%
	Programmed	1	
	Fair	3	
	Poor	4	

A.3 Criticality

To calculate the criticality of all assets and all hazards, the risk assessment used a geospatial analysis of five indicators: traffic volume, functional classification, truck traffic volume, location relative to CEJEST disadvantaged communities, and National Highway System designation. **Table 33** summarizes these indicators, the values used to assign the score, and the weight of the indicator in the overall exposure score.

Table 33. Criticality Scoring Approach for All Assets and All Hazards

Indicator	Indicator Value	Score	Weight
Traffic Volume[xcv]	0 to 25th percentile	1	15%
	25th to 50th percentile	2	
	50th to 75th percentile	3	
	75th to 100th percentile	4	
Functional Classification[xcvi]	0 or uncoded – not a certified public road	1	15%
	7 – Local	1	
	6 – Minor collectors	2	
	5 – Major collectors	2	
	4 – Minor arterials	3	
	3 – Other principal arterials	3	
	2 – Other freeways	3	
	1 – Interstates	4	
Truck Traffic Volume[xcvii]	0 to 25th percentile	1	15%
	25th to 50th percentile	2	
	50th to 75th percentile	3	
	75th to 100th percentile	4	
Location within CEJST Disadvantaged Community[xcviii]	Not located within CEJST Disadvantaged Community	1	40%
	Located within CEJST Disadvantaged Community	4	
National Highway System[xcix]	0 – This section is not on the National Highway System.	1	15%
	1 – This section is on the National Highway System but is not a National Highway System intermodal connector.	4	
	2 – Major Airport	4	
	3 – Major Port Facility	4	
	4 – Major Amtrak Station	4	
	5 – Major Rail/Truck Terminal	4	
	6 – Major Intercity Bus Terminal	4	
	7 – Major Public Transit or Multi-modal Passenger Terminal	4	
	8 – Major Pipeline Terminal	4	
	9 – Major Ferry Terminal	4	

Appendix B: Data Sources

The following tables provide information on the indicators and sources used for each asset type across the hazards assessed.

B.1 Exposure

Table 34. Exposure Indicators and Sources for Riverine and Coastal Flooding for All Assets

Indicator	Source	Source Notes	Available Statewide?
Past flood experience	MDOT – Statewide Transportation Operations Center & MDOT – Hydraulics Unit [c]	Joe McAttee provided statewide flooding data from 2015 to 2022. Erik Carlson provided additional past flood data via email.	No
FEMA Flood Zone	FEMA Flood Map Service Center | Search All Products[ci]	N/A	Digital maps not available statewide
Change in Days with Precipitation >3 inches	University of Wisconsin-Madison, Nelson Institute for Environmental Studies – Dynamic Downscaling for the Midwest and Great Lakes Basin[cii]	Risk assessment used mid-21st century for period of change and calculated the average change in days based on the six climate models.	Yes

Table 35. Exposure Indicators and Sources for Stormwater Flooding for All Assets

Indicator	Source	Source Notes	Available Statewide?
Past flood experience	MDOT – Statewide Transportation Operations Center[ciii]	Joe McAttee provided statewide flooding data from 2015 to 2022. Erik Carlson provided additional past flood data via email.	No
Impervious surface percentage within watershed	NLCD Imperviousness (CONUS) All Years | Multi-Resolution Land Characteristics (MRLC) Consortium[civ]	GIS analysis calculated percentage impervious for each watershed. Assets not within Michigan's Major Watershed Subbasin layer were scored as a 1.	Yes
Change in Days with Precipitation > 3 inches	University of Wisconsin-Madison, Nelson Institute for Environmental Studies –	Risk assessment used mid-21st century for	Yes

Indicator	Source	Source Notes	Available Statewide?
	Dynamic Downscaling for the Midwest and Great Lakes Basin[cv]	period of change and calculated the average change in days based on the six climate models.	

Table 36. Exposure Indicators and Sources for Coastal Erosion for All Assets

Indicator	Source	Source Notes	Available Statewide?
Location relative to high-risk erosion zones	High Risk Erosion Zones | State of Michigan (arcgis.com)[cvi]	N/A	Yes

Table 37. Exposure Indicators and Sources for Heat for Roadways and Bridges

Indicator	Source	Source Notes	Available Statewide?
Impervious surface percentage within watershed	NLCD Imperviousness (CONUS) All Years | Multi-Resolution Land Characteristics (MRLC) Consortium[cvii]	GIS analysis calculated percent impervious for each watershed. Assets not within Michigan's Major Watershed Subbasin layer were scored as a 1.	Yes
Change in days above 90°F	University of Wisconsin-Madison, Nelson Institute for Environmental Studies – Dynamic Downscaling for the Midwest and Great Lakes Basin[cviii]	Risk assessment used mid-21st century for period of change and calculated the average change in days based on the six climate models.	Yes
Heat severity (Source: Trust for Public Land)	Heat Severity - USA 2021 | HEAT.gov - National Integrated Heat Health Information System[cix]	N/A	Yes

B.2 Sensitivity

Table 38. Sensitivity Indicators and Sources for Riverine/Coastal and Stormwater Flooding for Roadways

Indicator	Source	Source Notes	Available Statewide?
Pavement Condition	Pavement Condition Measures (2022) | State of Michigan (arcgis.com)[cx]	Field: PcmRating	Not available for all roads

Table 39. Sensitivity Indicators and Sources for Heat for Roadways

Indicator	Source	Source Notes	Available Statewide?
Pavement Condition	Pavement Condition Measures (2022) | State of Michigan (arcgis.com) [cxi]	Field: PcmRating	Not available for all roads
Pavement Material	MDOT RH 2023 GDB | State of Michigan (arcgis.com) [cxii]	Field: MIRESurfaceType	Not available for all roads

Table 40. Sensitivity Indicators and Sources for Riverine/Coastal and Stormwater Flooding for Bridges

Indicator	Source	Source Notes	Available Statewide?
Bridge Condition	Bridge Condition | State of Michigan (arcgis.com) [cxiii]	Field: LowestRating	Yes
Bridge Age	Bridge Condition | State of Michigan (arcgis.com) [cxiv]	Fields: YEARBUILT, YEARRECON	Yes
Scour Criticality	Bridge Condition | State of Michigan (arcgis.com) [cxv]	Field: ITEM113	Yes

Table 41. Sensitivity Indicators and Sources for Heat for Bridges

Indicator	Source	Source Notes	Available Statewide?
Bridge Condition	Bridge Condition | State of Michigan (arcgis.com) [cxvi]	Field: LowestRating	Yes
Bridge Age	Bridge Condition | State of Michigan (arcgis.com) [cxvii]	Fields: YEARBUILT, YEARRECON	Yes

Table 42. Sensitivity Indicators and Sources for Pump Stations for Riverine/Coastal and Stormwater Flooding

Indicator	Source	Source Notes	Available Statewide?
Access Issues	Pump station access issue information provided via Excel document by MDOT and Wayne County staff.[cxviii]	N/A	No
Pump Station Age	Pump station age information provided via Excel document by MDOT staff. [cxix]	N/A	Yes
Pump Station Condition	Pump station condition information provided via Excel document by MDOT staff. [cxx]	N/A	Yes

B.3 Criticality

Table 43. Criticality Indicators and Sources for All Assets and All Hazards

Indicator	Source	Source Notes	Available Statewide?
Traffic Volume	Roads, pump stations, culverts: MDOT RH 2023 GDB | State of Michigan (arcgis.com)[cxxi] Bridges: National Bridge Inventory | Geospatial at the Bureau of Transportation Statistics (bts.gov)[cxxii]	Field for roads, pump stations, culverts: AADT Field for bridges: ADT	Yes
Functional Classification	Roads, pump stations, culverts: MDOT RH 2023 GDB | State of Michigan (arcgis.com)[cxxiii] Bridges: National Bridge Inventory | Geospatial at the Bureau of Transportation Statistics (bts.gov)[cxxiv]	Roads, pump stations, culverts: NFC Bridges: FUNCTIONAL_CLASS_026	Yes
Truck Traffic Volume	Roads, pump stations, culverts: 2021 Traffic Volumes | State of Michigan (arcgis.com)[cxxv] Bridges: National Bridge Inventory | Geospatial at the Bureau of Transportation Statistics (bts.gov)[cxxvi]	Field for roads, pump stations, culverts: AadtCommercial Field for bridges: PERCENT_ADT_TRUCK_109 (value given as a percent of total traffic volume)	Yes
Location within CEJEST Disadvantaged Community	Downloads - Climate & Economic Justice Screening Tool (geoplatform.gov)[cxxvii]	N/A	Yes
National Highway System	Roads, pump stations, culverts: MDOT RH 2023 GDB | State of Michigan (arcgis.com)[cxxviii] Bridges: National Bridge Inventory | Geospatial at the Bureau of Transportation Statistics (bts.gov)[cxxix]	Field for roads, pump stations, and culverts: National Highway System Field for Bridges: HIGHWAY_SYSTEM_104	Yes

Appendix C: Priority Projects

The following tables list MDOT's priority resilience projects to support the implementation of strategies contained within this Resilience Improvement Plan. **Table 44** includes projects currently slated to use PROTECT Formula Program funding, and **Table 45** includes resilience projects that are currently slated to use Surface Transportation Block Grant funding. Additional details on these projects can be found in the accompanying spreadsheets.

These tables and accompanying spreadsheets represent information as of June 2024, and as such, the details are subject to change (e.g., funding decisions, project start and end dates, and project scopes). As MDOT implements this Resilience Improvement Plan, the department intends to update these lists periodically to accommodate potential changes.

Table 44. Priority Projects Using PROTECT Funding

Title	County	Work Description	Location	PROTECT Amount
Bridge - Big Bridge Program	Bay	Bridge replacement	Over the East Channel of the Saginaw River	$10,160,000
Road - Rehabilitation and Reconstruction	Genesee	Road reconstruction and bridge replacement	Flint River to Carpenter Road	$3,311,914
Trunkline Modernization I-94 Detroit	Wayne	I-94 drainage agreement to create a resilient drainage system	Various locations adjacent to the I-94 Mega Project	$1,375,547
Trunkline Modernization I-94 Detroit	Wayne	I-94 drainage agreement to create a resilient drainage system	Various locations adjacent to the I-94 Mega Project	$1,130,305
Trunkline Modernization I-94 Detroit	Wayne	I-94 drainage agreement to create a resilient drainage system	Various locations adjacent to the I-94 Mega Project	$400,000
Trunkline Modernization I-94 Detroit	Wayne	I-94 drainage agreement to create a resilient drainage system	Various locations adjacent to the I-94 Mega Project	$28,682,636
N/A	Berrien	Revetment restoration for shoreline protection	Hawthorne Avenue to CSX Railroad, City of St. Joseph	TBD

Table 45. Priority Resilience Projects Using Surface Transportation Block Grant Funding

Major Route	County	Work Description	Location	Total Cost
M-53	Macomb	Deep overlay, beam repairs, railing replacement, approach work	Six structures between 18 Mile Road and M-59	$8,763,790
M-53 N	Macomb	Bridge railing replacement, epoxy overlay, joint repair, scour, bridge approach	Over Beaver Creek, City of Warren	$2,763,691
M-66	Osceola	Substructure repair	Over the Muskegon River	$1,798,787
M-43	Barry	Bridge replacement	Over the Coldwater River	$5,751,000
US-10	Bay	Overlay - shallow	Two Structures on US-10	$2,292,560
US-127	Gratiot	Overlay - shallow (polymer)	Over Bad River	$1,731,250
M-25	Sanilac	Soil stabilization	Frenchline Road	$8,765,013
I-196	Van Buren	Culvert replacement, roadway reconstruction, riprap, guardrail	Over Rogers Creek, Covert Township, Van Buren County	$8,354,200
M-66	Barry	Deck replacement	Over Quaker Brook (08052-B02)	$1,130,000
M-66	Osceola	Bridge replacement	M-66 over Doc and Tom Creek (67031-B01)	$4,273,000
US-10	Osceola	Deep overlay and HMA overlay	US-10 and US-10 Business Route over the Hersey River	$2,971,300
Countywide	Gladwin	Scour protection	4 bridges in Gladwin County	$897,936
M-11	Kent	Scour repair	2 structures located on M-11 & I-96 EB	$666,000
US-131	Montcalm	Culvert replacement	Over No. 102 Drain	$6,342,000
Countywide	Wayne	Installation of permanent standby generators	17 pump stations within Wayne County	$9,800,000
US-31	Mason	Scour countermeasures	US-31 over Freeman Creek	$283,035
Statewide	N/A	Installation of permanent standby generators at stormwater pump stations	Statewide FRF ID # FRF3864	$29,900,000
I-94 W	Wayne	I-94 drainage agreement to create a resilient drainage system	Various locations adjacent to the I-94 Mega Project	$39,485,610
Statewide	N/A	Installation of permanent standby generators at stormwater pump stations	Statewide FRF ID # FRF3864	$35,800,000
Statewide	N/A	Installation of permanent standby generators at stormwater pump stations	Statewide	$1,500,000

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