KENTUCKY TRANSPORTATION CABINET

DECEMBER 2025

TABLE OF CONTENTS:

CHAPTER 1: INTRODUCTION 1

» 1.1: RESILIENCE & THE TRANSPORTATION SYSTEM 3

» 1.2: EXTREME WEATHER AND NATURAL HAZARDS IN KENTUCKY 5

» 1.3: PURPOSE AND REQUIREMENTS OF A RESILIENCE IMPROVEMENT PLAN 7

» 1.4: RIP ORGANIZATION 9

CHAPTER 2: COORDINATION WITH OTHER PLANS 11

» 2.1: KYTC TRANSPORTATION ASSET MANAGEMENT PLAN 13

» 2.2: KYTC LONG RANGE STATEWIDE TRANSPORTATION PLAN 14

» 2.3: KYTC FREIGHT PLAN 15

» 2.4: COMMONWEALTH OF KENTUCKY ENHANCED HAZARD MITIGATION PLAN. 16

» 2.5: CURRENT AND FUTURE ENACTED HIGHWAY PLANS 17

» 2.6: OPERATIONAL PLAN 18

» 2.7: RELATED RESEARCH AND STUDIES 19

CHAPTER 3: CLIMATE AND GEOLOGIC HAZARDS 21

» 3.1: NATURAL HAZARDS 24

» 3.2: CLIMATE PROJECTIONS 33

» 3.3: RISK-BASED VULNERABILITY ASSESSMENT 34

CHAPTER 4: RESILIENCE IN ACTION 39

» 4.1: MITIGATE 43

» 4.2: PREPARE 48

» 4.3: RESPOND 49

» 4.4: RECOVER 51

CHAPTER 5: FUTURE RESILIENCE STRATEGIES 53

- 5.1: AGENCY POLICY & GUIDANCE 55
- 5.2: STAFF RESOURCES & KNOWLEDGE 55
- 5.3: COMMUNICATION 56
- 5.4: PERFORMANCE MONITORING 56
- 5.5: PROJECT PROGRAMMING. 56
- 5.6: IMPLEMENTATION OF FUTURE ADAPTATION NEEDS 57
- 5.7: RISK-BASED DECISION-MAKING 57
- 5.8: FUNDING 57
- 5.9: PROJECT DEVELOPMENT 58
- 5.10: EMERGENCY RESPONSE. 59

CHAPTER 6: CONCLUSION 61

APPENDICES 65

LIST OF FIGURES:

FIGURE 1: DISASTER DECLARATIONS IN KENTUCKY, 1980-2025 5

FIGURE 2: TORNADO DAMAGE IN MAYFIELD, KY. 5

FIGURE 3: FLOODING IN JACKSON, KY. 6

FIGURE 4: FALLEN TREE AND POWERLINES OVER ROAD IN WOLFE COUNTY 6

FIGURE 5: AVERAGE ANNUAL DAYS WITH >3" PRECIPITATION 24

FIGURE 6: AVERAGE ANNUAL DAYS WITH TEMPERATURE > 95 DEGREES 27

FIGURE 7: BREAKDOWN BY HAZARD 38

FIGURE 8: FOUR PHASES OF EMERGENCY MANAGEMENT AS IT RELATES TO RESILIENCE 41

FIGURE 9: BRIDGE VULNERABILITY SCORING INDICES. 46

FIGURE 10: KYTC ESTIMATED REPAIR COSTS BY YEAR FOR DECLARED DISASTERS BETWEEN 2009 - 2022 51

LIST OF TABLES:

TABLE 1: RISK MATRIX. 35

TABLE 2: RISK SCORE RESULTS 36

TABLE 3: ASSET-LEVEL ASSESSMENT 37

TABLE 4: POTENTIAL CRITICAL TRANSPORTATION ASSETS TO CONSIDER IN FUTURE RIP UPDATES . . . 63

Welcome To
Kentucky
UNBRIDLED SPIRIT
Andy Beshear, Governor

Chapter 1

1.1: RESILIENCE & THE TRANSPORTATION SYSTEM

Resilience is the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions. For Kentucky's transportation system, resilience translates into the ability to keep roads open and functional when unexpected, challenging conditions occur – including natural and human-caused disasters. Transportation resilience is a key component of the Kentucky Transportation Cabinet's (KYTC) mission, and KYTC has been investing in resilience efforts for many years.[1]

1.1.1: BENEFITS OF RESILIENCE

Understanding the importance of resilience in transportation infrastructure is vital for the safety and well-being of Kentucky's residents. By building resilience into the framework of the transportation system, Kentucky is not only safeguarding roads and bridges but also ensuring that communities remain connected and accessible during times of crisis.

The resilience of the transportation network goes beyond merely designing and constructing physical structures to withstand extreme weather events and natural hazards; it encompasses the entire spectrum of KYTC's operations, from planning and strategic maintenance to effective emergency response and recovery. By adopting a comprehensive approach, KYTC can better anticipate potential disruptions, reduce vulnerabilities, and enhance the overall functionality of the transportation network.

KYTC is prepared to respond to impacts of weather events, natural disasters and changing conditions through coordination with other agencies, mitigation strategies, preparedness, and emergency response and recovery efforts. KYTC is a first response partner with Kentucky Emergency Management (KYEM) and local governments to deploy resources including personnel and equipment during impactful events. KYTC has significant planning and statewide communication experience, including year-round emergency response partner outreach and participation in emergency drills. After initial response, KYTC uses the impacts of weather and climate events to guide strategies and investment for the reconstruction and future operation of transportation infrastructure with consideration of resilience and potential future risk.

NATURAL AND HUMAN-MADE DISASTERS AFFECT TRANSPORTATION INFRASTRUCTURE, OPERATIONS, SAFETY, AND LIMIT MOBILITY, CREATING ECONOMIC IMPACTS.

INFRASTRUCTURE /OPERATIONAL IMPACTS

- Increased frequency and cost of maintenance and repairs
- More complex and demanding operational considerations

SAFETY IMPACTS

- Potential increase crash risk due to road conditions.
- Disruptions and reduced access to evacuation routes
- Increased emergency response times
- Potential elevated safety risk for field staff

MOBILITY AND ECONOMIC IMPACTS

- Travel delays due to detours and rerouting
- Disrupted access to destinations, especially in cases where detours become inaccessible
- Interruptions in the movement of goods and the facilitation of services, leading to financial losses for businesses and workers

[1] *A full description of the agency's response roles and responsibilities can be found in the Kentucky Transportation Cabinet All Hazards Response Plan developed by the Division of Incident Management.*

KYTC MISSION

The Kentucky Transportation Cabinet's mission is to provide a safe, efficient, environmentally sound, and fiscally responsible transportation system that delivers economic opportunity and enhances the quality of life in Kentucky.

1.2: EXTREME WEATHER AND NATURAL HAZARDS IN KENTUCKY

In recent years, Kentucky has experienced an array of natural disasters that have tested infrastructure and community resilience. The impacts of these events have underscored the necessity of integrating resilience into every facet of transportation planning and execution. By doing so, KYTC can mitigate the impacts of future hazards, ensuring that Kentucky's roads remain accessible and safe for all users.

Climate models predict conditions that will gradually change over the coming decades, compared to those encountered historically. For Kentucky, these models predict a warmer and wetter environment. While Kentucky's transportation infrastructure has been designed to handle a broad range of climate impacts based on historic observations and trends, there are questions about how the system will perform amid these environmental changes and the associated increased frequency of extreme weather events.

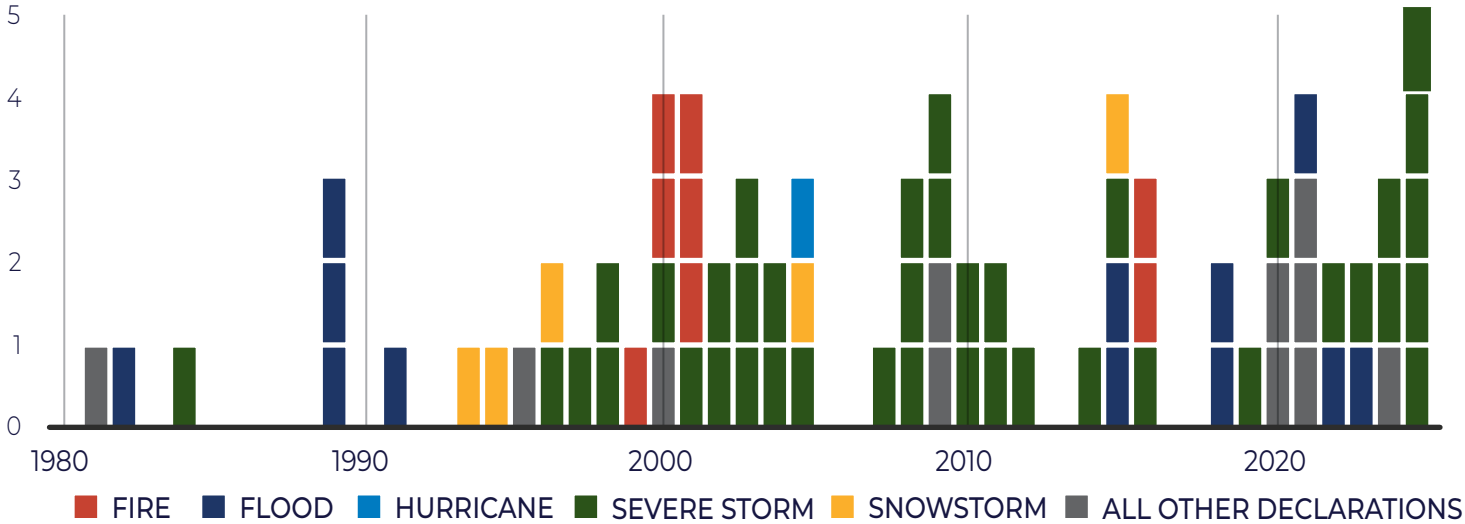
From 1980 to 1999, Kentucky averaged 0.7 presidentially declared disasters per year. Since 2000, that average has increased to 2.35 presidentially declared disasters per year. In 2024 and 2025 (through September) alone, there have been three and five presidentially declared disasters, respectively **(Figure 1)**.

Recent events in Kentucky have demonstrated the devastating power of extreme weather events and natural hazards.

FIGURE 2: TORNADO DAMAGE IN MAYFIELD, KY

In December 2021, western Kentucky was struck by a severe tornado outbreak that killed eighty people and destroyed or badly damaged more than fifteen thousand homes and businesses, resulting in damages estimated at upwards of four billion dollars. Cities such as Mayfield, Princeton, and Dawson Springs suffered catastrophic damage **(Figure 2)**.

FIGURE 1: DISASTER DECLARATIONS IN KENTUCKY, 1980-2025



Source: OpenFEMA, FEMA web disaster summaries, Federal Emergency Management Agency. Data analysis and processing by USAFacts. Retrieved on September 3, 2025. https://usafacts.org/answers/how-many-disasters-are-declared-in-the-us/state/kentucky/

FIGURE 3: FLOODING IN JACKSON, KY

FIGURE 4: FALLEN TREE AND POWERLINES OVER ROAD IN WOLFE COUNTY

The disaster in western Kentucky was followed in July 2022 by catastrophic flash flooding in eastern Kentucky. Up to sixteen inches of rain fell over the rugged terrain of Breathitt, Clay, Knott, Letcher, and Perry Counties, causing water to rise rapidly and violently in communities located along streams in low-lying areas **(Figure 3)**. The flash flooding killed forty-four people, damaged or destroyed over thirteen thousand homes, and critically damaged infrastructure such as roads, bridges, water supply, and power lines.

Additional flooding events have taken place since the major flooding in July 2022. In February 2025, certain areas such as Martin County received over nine inches of rainfall within several days. Over 300 roads were closed in Eastern Kentucky and numerous residents were displaced. In April 2025, ten inches of rain fell across Central and Northern Kentucky, causing rivers, including the Ohio River, to rise and overflow their banks. Cities and towns including Frankfort, Butler, Falmouth, and Louisville were among those affected during this flooding.

Winter storms have also impacted Kentucky communities, including the January 2025 storm that brought snow and ice across the Commonwealth. Snowfall began early on the 5th with rates up to 1 inch per hour, while freezing rain later caused severe icing—up to 0.75 inches—especially along the US-460 corridor. The storm led to extensive power outages across Menifee, Morgan, Johnson, and Martin counties, with restoration taking until January 11. Snow accumulations ranged from 3–7 inches northeast of US-421, and significant tree damage occurred due to ice. Trees and fallen powerlines affected road access and travel **(Figure 4)**.[2]

INCREASING NATURAL HAZARDS

These events are part of an ongoing pattern of more frequent extreme weather events affecting Kentucky communities and placing additional demands on public agency resources. Each of these events has presented unique challenges to the safety, reliability, effectiveness, and sustainability of transportation infrastructure and operations.

[2] *National Weather Service. (2025, January 6). Eastern Kentucky's first winter storm of 2025. Weather.gov. https://www.weather.gov/jkl/2025-01-05-06-EasternKentucky-FirstWinterStorm2025*

1.3: PURPOSE AND REQUIREMENTS OF A RESILIENCE IMPROVEMENT PLAN

A Resilience Improvement Plan (RIP) is meant to address surface transportation system resilience to current and future weather events and natural disasters. The goal of this Resilience Improvement Plan is to better prepare Kentucky to respond to and withstand future extreme weather and natural hazard events in order to provide a more resilient transportation system. RIPs are not a federal requirement for transportation agencies. However, agencies are encouraged to develop a RIP in accordance with 23 U.S.C. Section 176(e) – **Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation (PROTECT) program**. The PROTECT program provides grants for resilience improvements through formula funding distributed to states and discretionary competitive grants. Agencies that have developed an eligible plan qualify for a lower non-federal match from the FHWA PROTECT Formula Program.

RIPs include a vulnerability assessment of transportation assets to potential natural hazard risks and strategies to address the risks identified. The Infrastructure Investment and Jobs Act (IIJA), the federal legislation that established RIPs, identifies the criteria as requirements for an eligible RIP in 23 USC §176.

This RIP demonstrates KYTC's proactive commitment to safeguarding the Commonwealth's transportation infrastructure by identifying system vulnerabilities, applying risk-informed strategies, and prioritizing targeted improvements. It meets all the FHWA requirements, as well as several optional elements (except those noted at the right). Serving as both a strategic framework and a catalyst for action, this Plan consolidates the agency's resilience initiatives and charts a path toward a more adaptive, integrated, and forward-looking resilience planning program.

RIP CRITERIA

A RIP Shall...

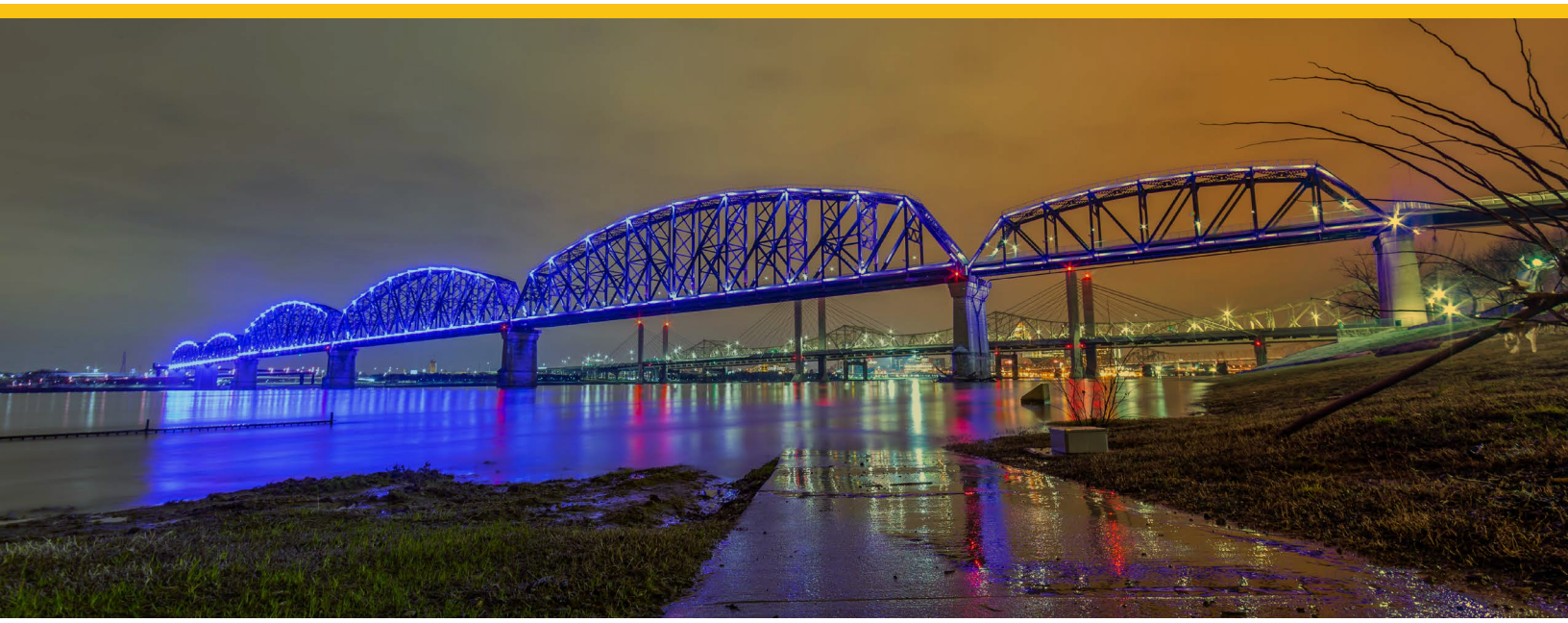
- Be for the immediate and long-range planning activities and investments of the State with respect to transportation system resilience.
- Demonstrate a systemic approach to surface transportation system resilience and be consistent with and complementary of the State and local mitigation plans required under section 322 of the Robert T. Stafford Disaster Relief and Emergency Assistance Act (42 U.S.C. 5165)
- Include a risk-based assessment of vulnerabilities of transportation assets and systems 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 temperatures), and earthquakes. The risk-based assessment should consider both the probability of assets being affected by future weather and disasters as well as the consequences of those events.

Shall, as appropriate…

- Include a description of how the agency is prepared to respond to the impacts of weather events, natural disasters and is prepared for changing conditions.
- Describe the codes, standards, and regulatory framework, adopted and enforced by the agencies, to ensure that resilience improvements within the impacted area of proposed projects that are included in the plan.
- Consider the benefits of combining hard surface transportation assets, and natural infrastructure, through coordinated efforts by the Federal Government and the States.
- Assess the resilience of other community assets, including buildings and housing, emergency management assets, and energy, water, and communication infrastructure.

A RIP may…

- Designate evacuation routes and strategies, including multimodal facilities, designated with consideration for individuals without access to personal vehicles. (Not included in KYTC's RIP)
- Plan for response to anticipated emergencies, including plans for the mobility of emergency response personnel and equipment and access to emergency services, including for vulnerable or disadvantaged populations.
- Describe the resilience improvement policies, including strategies, land-use and zoning changes, investments in natural infrastructure, or performance measures that will inform the transportation investment decisions of the State or metropolitan planning organization with the goal of increasing resilience.
- Include an investment plan that includes a list of priority projects and describes how funds apportioned to the State under section 104(b)(8) or provided by a grant under the PROTECT program would be invested and matched, which shall not be subject to fiscal constraint requirements. (Not included in KYTC's RIP)
- Use science and data and indicate the source of data and methodologies.



Specifically,

THE PLAN WILL:

Be updated as ongoing and future resilience planning activities are completed, including the identification and documentation of specific projects that advance KYTC's resilience goals.

INFORM...

Cabinet resiliency policy to ensure alignment across departments and initiatives.

GUIDE...

Resilience investment strategy for planning, design, and asset management, enabling data-driven prioritization of infrastructure improvements.

PROVIDE...

References for resilience planning and response efforts within other agency plans.

OUTLINE ...

Resilience research roadmap for the Cabinet.

1.4: RIP ORGANIZATION

The RIP aligns itself with other KYTC plans **(Chapter 2)** and identifies the climate and geologic hazards affecting Kentucky **(Chapter 3)**. It then highlights the actions and initiatives KYTC has in place to support resilience **(Chapter 4)**, followed by a discussion of potential future strategies **(Chapter 5)**. The plan concludes with recommended next steps for implementing these strategies and updating the RIP **(Chapter 6)**. Below is an overview of each chapter. Key points are also listed at the beginning of each chapter.

RIP OUTLINE

CHAPTER 2

COORDINATION WITH OTHER PLANS:
Overview of how resilience is integrated into KYTC's existing plans and operations, including coordination with the Transportation Asset Management Plan (TAMP), Long Range Statewide Transportation Plan (LRSTP), Freight Plan, Enhanced Hazard Mitigation Plan (EHMP), and related research and studies.

CHAPTER 3

CLIMATE AND GEOLOGIC HAZARDS:
Description of Kentucky's vulnerability to natural hazards—such as flooding, severe storms, landslides, and earthquakes and sinkholes—paired with a risk-based assessment approach used to guide resilience planning.

CHAPTER 4

RESILIENCE IN ACTION:
Discussion of KYTC's database of damages, emergency response coordination, and ongoing research and asset management planning.

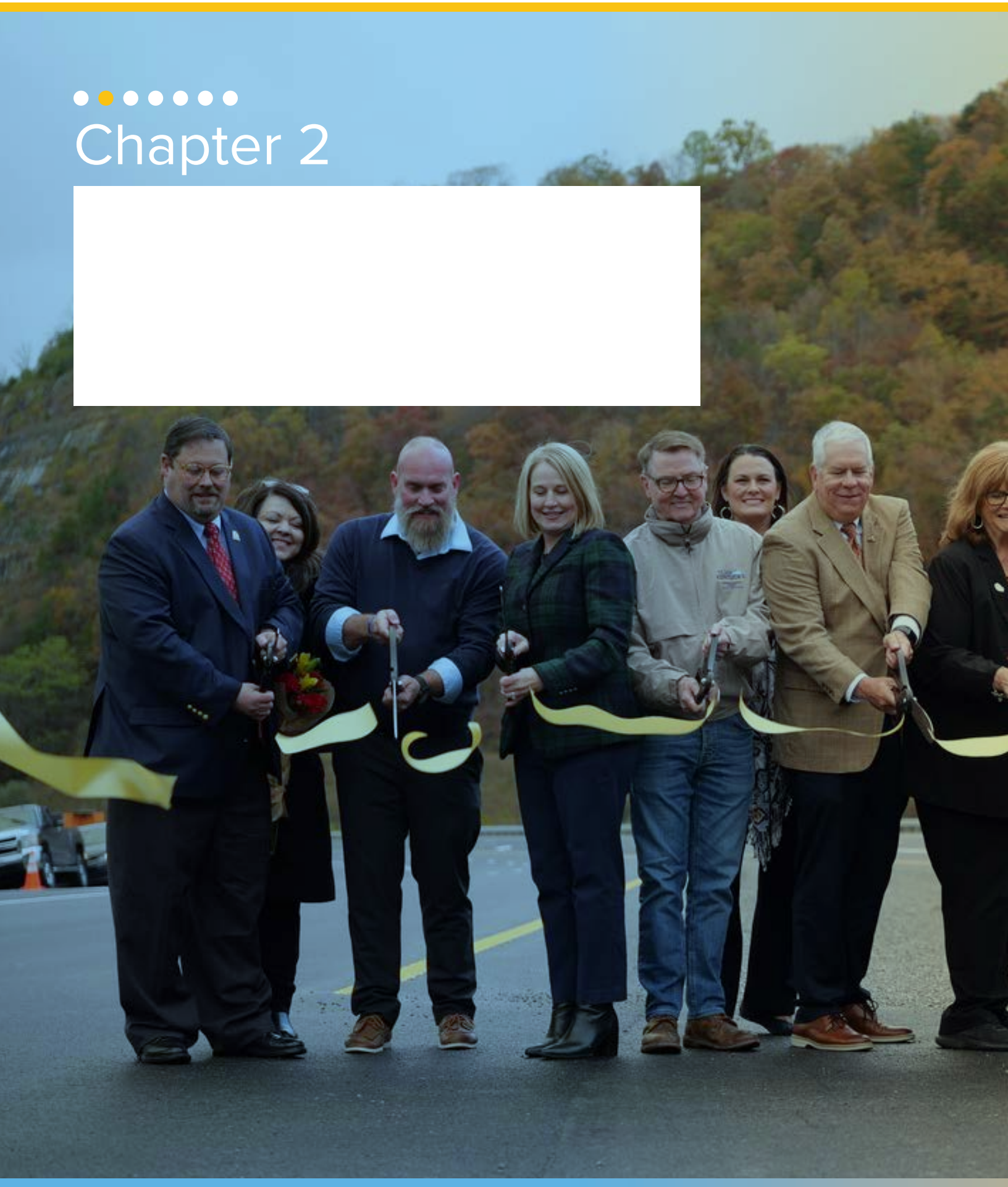
CHAPTER 5

FUTURE RESILIENCE STRATEGIES:
Summary of adaptation strategies for climate and extreme weather risks, including natural infrastructure solutions, design standards, and ongoing research efforts.

CHAPTER 6

CONCLUSION:
Outline of KYTC's future policy development, performance measures, cost modeling and plans to expand resilience efforts to other transportation modes and critical assets.

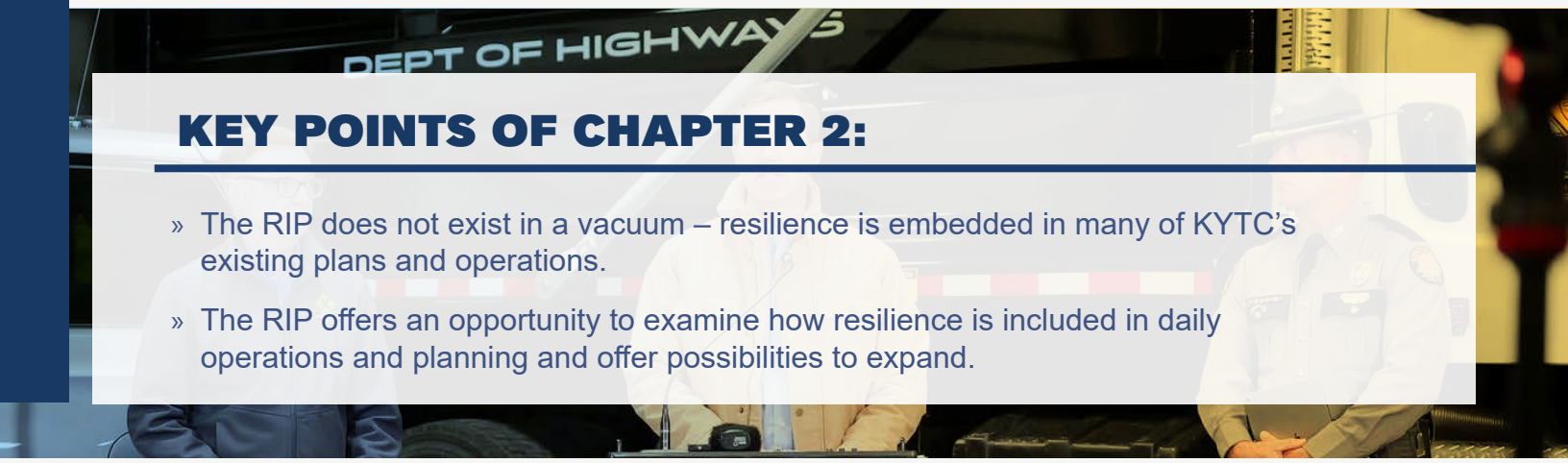
Chapter 2



U.S. 460 CORRIDOR RIBBON CUTTING

Celebrating one of the region's most transformative infrastructure investments: the U.S. 460 Corridor in Pike County. This project connects U.S. 23 to Virginia, enhancing 16.7 miles of roadway with 22 bridges, 5 interchanges; a milestone in coordination and progress for Eastern Kentucky.

Source: KYTC



KEY POINTS OF CHAPTER 2:

- The RIP does not exist in a vacuum – resilience is embedded in many of KYTC's existing plans and operations.
- The RIP offers an opportunity to examine how resilience is included in daily operations and planning and offer possibilities to expand.

The KYTC Resilience Improvement Plan has been developed and will be implemented in coordination with other agency-wide planning efforts, including the following plans:

2.1: KYTC TRANSPORTATION ASSET MANAGEMENT PLAN

KYTC's Transportation Asset Management Plan (TAMP) and program incorporate resilience-related objectives into agency decision-making. The TAMP, most recently updated in 2022, serves as a central resource for information on assets, management strategies, long-term expenditure forecasts, and business processes. The KYTC TAMP aligns with the Cabinet's policy directions and uses risk-based, performance-oriented analysis to deliver the most cost-effective investment strategy for the Commonwealth. These efforts support the Cabinet's mission, vision, goals, and accountability by:

- Minimizing annual system preservation costs.
- Maximizing system performance within budget constraints.
- Supporting objective, data-driven decision-making.
- Balancing expectations with available funding.

KYTC takes a holistic approach to building a resilient transportation network by integrating resilience strategies into the TAMP.

Examples include:

- Adapting pavement friction design to address increased precipitation during pavement life cycle.
- Prioritizing bridge asset management projects using an index that factors in scour risk and flood vulnerability.

This approach aims to reduce potential damage from environmental events and strengthen the overall resilience of Kentucky's transportation system.

2.2: KYTC LONG-RANGE STATEWIDE TRANSPORTATION PLAN

The 2022-2045 Long-Range Statewide Transportation Plan (LRSTP) is a multimodal plan for the next 20+ years, developed by KYTC as required by federal transportation reauthorization acts. The importance of having a resilient transportation system to the Commonwealth is apparent throughout the plan. The LRSTP's vision is to ensure "a viable, reliable, and resilient multimodal transportation system to provide access and mobility for all users for the safe movement of people and goods."

To achieve this vision, the LRSTP outlines five goals aligned with the seven national performance goals established in federal legislation:

- Enhance safety
- Deliver a high level of maintenance and resiliency
- Establish a reliable flow of people and freight
- Provide local, regional, and global connectivity for communities
- Deliver and operate a system that protects or enhances the natural and human environment

The plan also defines five guiding principles, each connected to resilience. One principle—adaptability/sustainability—explicitly addresses resilience. The LRSTP identifies challenges and vulnerable assets consistent with the RIP. Both direct and indirect transportation impacts are considered. The 2022-2045 LRSTP Climate Change Overview cites the RIP as the baseline document for resilience planning efforts and references its data and methodologies for analyzing climate trends and potential impacts.

FIVE GUIDING PRINCIPLES OF THE LRSTP

QUALITY OF LIFE:
Create a clean and efficient system that promotes healthy and fully engaged lifestyles while protecting the natural and human environment.

EQUITY:
Seek fairness in mobility and accessibility to meet the needs of all community members.

ADAPTABILITY/SUSTAINABILITY:
Develop and operate a system that can adjust to the potentially disruptive forces of advances in technology, funding challenges, or human-made and natural disasters.

SEAMLESSNESS:
Integrate connectivity across all modes to provide reliable trip choices for people and freight.

ECONOMIC VITALITY:
Deliver and operate a system that improves the ability of the Commonwealth to provide employment and market opportunities.

2.3: KYTC FREIGHT PLAN

One of KYTC's goals is to provide a safe, reliable, efficient, and effective transportation system for the movement of freight within the Commonwealth while connecting Kentucky to domestic and international markets. The 2022 Kentucky Freight Plan defines how KYTC will achieve that goal and emphasizes that an effective multimodal freight system must consider resilience to minimize economic disruptions and contributing to economic development.

Serving as a supplement to the LRSTP, the Freight Plan works in coordination with the RIP to ensure freight strategies align with broader resilience objectives. One goal specifically references resilience – "Improve the safety, security, and resilience of the national freight system."

THE FREIGHT PLAN DRIVES THESE EFFORTS BY:

- Documenting freight assets
- Identifying future needs
- Recommending strategic initiatives
- Devising implementation strategies

RESILIENCE IS ALSO IDENTIFIED IN THE FUTURE NEEDS OF THE FREIGHT SYSTEM:

REDUNDANCY/RESILIENCY:

Build resiliency and redundancy into the freight transportation system to protect current and future investments and to maintain safe operational capabilities during and after extreme weather events or earthquakes. Adaptation of vulnerable freight transportation infrastructure and facilities will require policy changes and investment.

MOBILITY:

The routes identified as critical freight corridors are within KYTC's span of control and should become a known part of the planning process.

ENVIRONMENTAL IMPACT:

The amount of freight moving through Kentucky is anticipated to continue to increase; without intervention the emissions from this movement will also continue to increase. There is a need for enhanced efficiency across all modes of freight movement to reduce these environmental impacts including climate change, air pollution, stormwater runoff, and wildlife habitat preservation.

2.4: COMMONWEALTH OF KENTUCKY ENHANCED HAZARD MITIGATION PLAN

Hazard mitigation planning reduces loss of life and property by minimizing the impact of disasters. It begins with state, tribal, and local governments identifying natural disaster risks and vulnerabilities that are common in their area and documenting them in a hazard mitigation plan. Kentucky's latest hazard mitigation plan dates from 2023 and is called the Enhanced Hazard Mitigation Plan (EHMP).

Kentucky is one of only fifteen states to earn FEMA approval for an EHMP. To receive approval of an enhanced plan, a state must show that it has developed a comprehensive mitigation program and can manage increased funding for its mitigation goals.

The EHMP develops long-term strategies to protect people and property and break the cycle of disaster damage and reconstruction. It covers community infrastructure, agriculture, and population, which falls outside the initial scope of the RIP, which focuses primarily on major transportation assets.

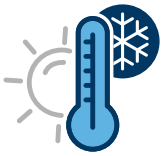
The EHMP hazard identification and repeated loss assessments use data sets and methodologies that are consistent with those in the RIP. This shared analytical foundation enables resiliency strategies to be applied to local assets through regional planning districts and mitigation programs, in coordination with Emergency Management.

While the RIP concentrates on natural hazards with higher probability and robust data for risk assessment, the EHMP addresses additional hazards such as dam failure and mine subsidence. Despite these differences, mitigation strategies identified in both plans align closely, ensuring a unified approach to reducing risk and enhancing resilience.

THE PLAN ADDRESSES A WIDE RANGE OF HAZARDS, INCLUDING:

- Dam failure
- Drought
- Earthquakes
- Extreme temperatures
- Flooding
- Karst/Sinkholes
- Landslides
- Mine subsidence
- Wildfires
- Wind
- Winter storms

EARTHQUAKES



EXTREME TEMPERATURES

FLOODING

LANDSLIDES

SEVERE WINTER STORMS (SNOW AND ICE)

SEVERE THUNDERSTORMS (WIND, HAIL, AND TORNADOES)

SINKHOLES

WILDFIRES

2.5: CURRENT AND FUTURE ENACTED HIGHWAY PLANS

The Enacted Highway Plan is Kentucky's official six-year roadmap for transportation investments. It includes the Biennial Highway Plan for the upcoming two years and recommended projects for the following four years. Projects are prioritized using asset management and performance measures for pavement, bridges, and guardrails, along with considerations for safety, economic growth, congestion relief, and connectivity. The plan is fiscally balanced against anticipated state and federal funding. In accordance with state law, the Governor submits a Recommended Highway Plan to the General Assembly in January of each even-numbered year, and the legislature enacts the final plan by April 15. KYTC publishes the official version in June.

The 2024-2030 Enacted Highway Plan plays a critical role in addressing resilience concerns focusing especially on highway damage and service disruptions. Of the three major investment categories recommended in the plan, two – asset management and capacity improvements – explicitly note the concern for resilience in the investment descriptions.

THE LATEST PLAN REINFORCES KYTC'S...

Commitment to a risk-based asset management approach, stating: "This approach reflects the Cabinets strong commitment to its **Transportation Asset Management (TAM) framework,** which:

- Links planned investments to performance expectations
- Extends the service life of the transportation system economically using low-cost treatment early in an asset's service life
- Reduces agency risk and exposure from unplanned events such as flooding
- Enhances system resilience

2.6: OPERATIONAL PLAN

The Kentucky Transportation Cabinet (KYTC) Operational Plan outlines a clear vision to improve transportation systems, foster economic growth, and enhance the quality of life for Kentuckians. The plan focuses on five key goals: prioritizing safety, strengthening stakeholder relationships, delivering economic opportunities, optimizing performance through innovation, and nurturing a culture where every voice matters.

Establishing tangible goals forms the backbone of their strategic blueprint. The framework established in the KYTC Operations Strategic Planning document allows the agency to successfully navigate anticipated challenges that may reshape Kentucky's transportation system, such as the increased use of new technologies in the transportation sector, increased traffic volumes, and uncertainty related to asset resilience.

The Operational Plan is a dynamic document that is periodically revised to maintain the agency's effective response to new and unexpected challenges.

THE OPERATIONAL PLAN RECOGNIZES ...

Delivering a safe, resilient transportation network and innovative practices is closely linked to the five KYTC values. **The importance of a resilient transportation network** is acknowledged in Goal 3: Deliver Economic Opportunities and Enhance Quality of Life.

Strategies to achieve Goal 3 include:

- Improving mobility and access
- Invest in improvements across all modes of transportation
- Pursue methods of modernizing revenue

INVEST IN IMPROVEMENTS ACROSS ALL MODES OF TRANSPORTATION:

The tactics identified under this strategy align with the desire to improve coordination on resilience needs and emergency management during disasters. Improving local coordination and restoring collaboration with local emergency and incident management officieals are two of the tactics identified.

2.7: RELATED RESEARCH AND STUDIES

2.7.1: KENTUCKY TRANSPORTATION CENTER RESEARCH

KYTC has been a national leader in studying potential natural hazard risks to state transportation systems. In partnership with the Kentucky Transportation Center (KTC)—the research arm of the University of Kentucky—KYTC has undertaken several significant research initiatives to advance resilience planning and risk management. These are listed below and described in more detail in later sections as noted in each summary.

KTC is developing a proposed risk-based vulnerability assessment approach that assigns monetary values to asset risks. This method will equip KYTC officials with a more effective tool for comparing the relative resilience benefits of different projects. It will also provide a clear, quantifiable metric for communicating the value of resilience-related investments to key external stakeholders and the general public.

Transportation System Vulnerability and Resilience to Extreme Weather Events and other Natural Hazards, Pilot Project — KYTC District 1 (2016) — This study provided an initial framework for vulnerability assessments and documented natural hazards likely to affect Kentucky's National Highway System (NHS) in District 1 (Western Kentucky). For more information see Section 3.2.1.

Transportation System Vulnerability and Resilience to Extreme Weather Events and Other Natural Hazards - Final Results of Vulnerability Assessment of National Highway System for All KYTC Districts (2018) — Building on the pilot in District 1, KYTC conducted a comprehensive statewide study to evaluate NHS vulnerabilities across all districts. For more information see Section 3.2.1.

Asset Management, Extreme Weather, and Proxy Indicators (2019) – This pilot study focused on establishing a framework to identify asset risks related to natural hazards and incorporate such information into the KYTC asset management system. The intent was to support the identification of mitigation strategies that could prolong the useful life of NHS assets, and develop a risk-based asset management program as required by federal regulations. The study examined two major climate threats—higher temperatures and more precipitation—and their potential impacts on two major asset types—pavements and bridges. Three research efforts were conducted to provide the basis for developing the desired framework. The first was the development of a screening tool that leveraged National Bridge Inventory (NBI) data fields for identifying bridge and large culvert sensitivity to flooding. The second research effort developed a methodology for using temperature projections from climate models for pavement design with the Mechanistic Empirical Pavement Design (PME) software. The third research effort assessed current KYTC asset management processes to identify areas where the consideration of resilience concerns could be enhanced.

2.7.2: RIP TRANSFORMATION PROJECT

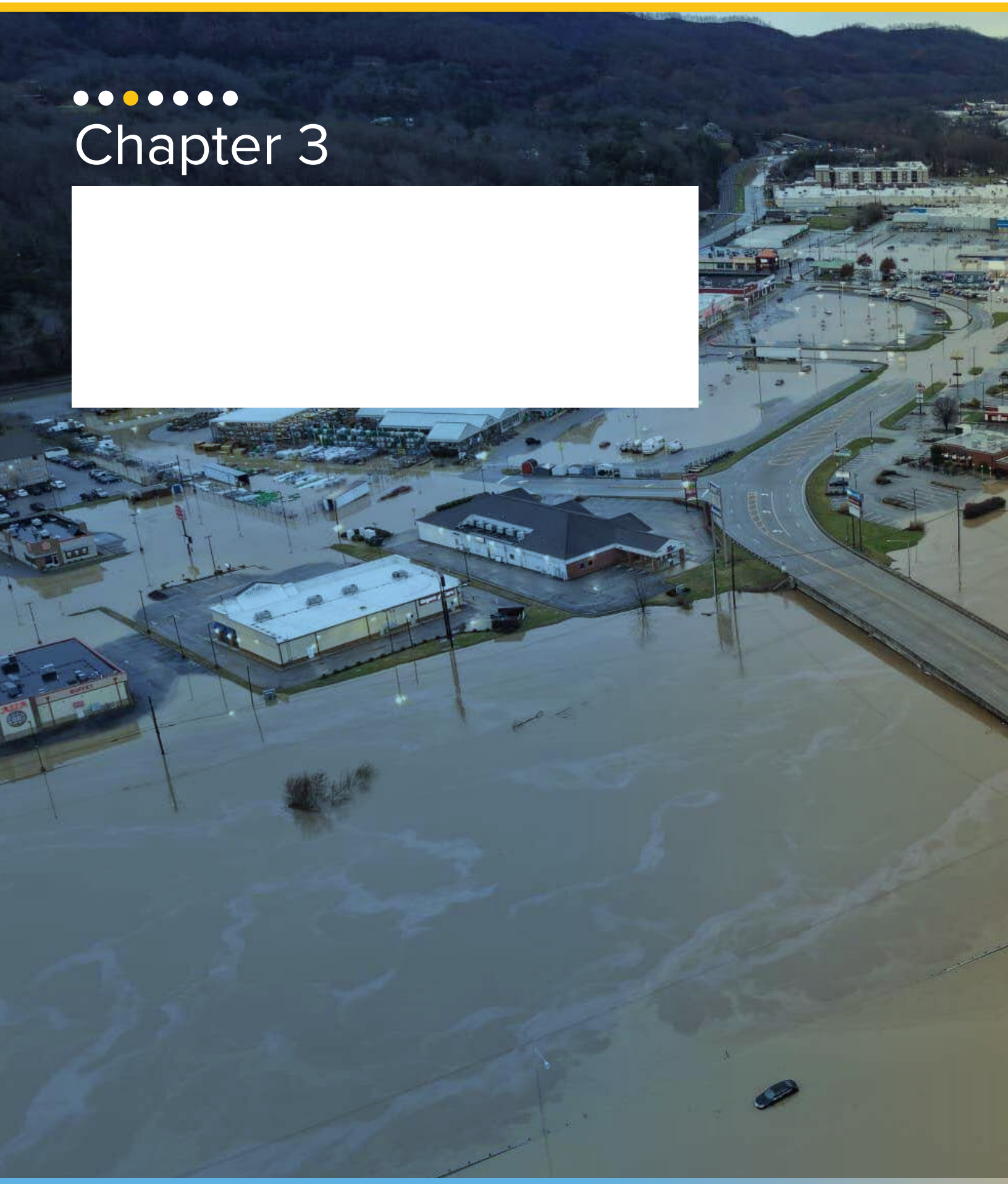
In 2024-2025, KYTC undertook a study to evaluate how resilience is embedded in its daily operations and to identify opportunities for strengthening those efforts. The study included five tasks:

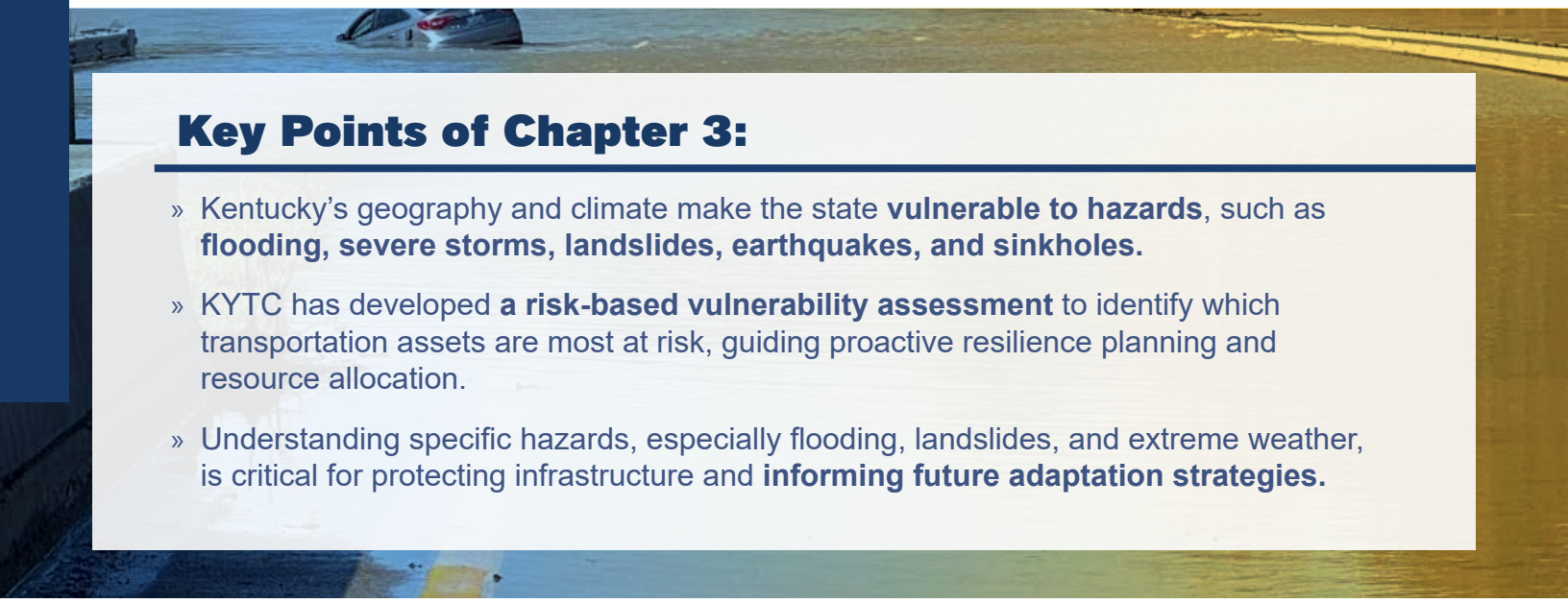
1. Examine the current status of resilience efforts within KYTC;
2. Identify potential resilience goals, objectives, and performance measures;
3. Identify resilience strategies and design solutions;
4. Develop an approach for identifying resilience-oriented projects from existing project lists; and
5. Propose guidance on preparing technical analyses in support of future KYTC assistance applications to the Federal Highway Administration's (FHWA's) Emergency Relief (ER) program[3].

KYTC and the consultant team held numerous meetings with staff, reviewed current legislation and technical guidance, and assessed existing plans and programs. Coordination with KTC —whose staff conducted complementary resilience studies and research—also informed the process. These efforts culminated in a set of recommendations to strengthen KYTC's resilience practices. This version of KYTC's RIP reflects updates based on the findings of the RIP Transformation Project.

[3] The FHWA ER Program provides federal funding to repair or reconstruct highways and bridges damaged by natural disasters or catastrophic events. It helps restore essential transportation services and supports quick recovery while ensuring repairs meet current standards.

Chapter 3





Key Points of Chapter 3:

- Kentucky's geography and climate make the state **vulnerable to hazards**, such as **flooding, severe storms, landslides, earthquakes, and sinkholes.**
- KYTC has developed **a risk-based vulnerability assessment** to identify which transportation assets are most at risk, guiding proactive resilience planning and resource allocation.
- Understanding specific hazards, especially flooding, landslides, and extreme weather, is critical for protecting infrastructure and **informing future adaptation strategies.**

Kentucky's geographic position at the heart of the eastern United States profoundly shapes its climate, landforms, and environmental challenges. The state experiences sharp seasonal contrasts, with hot, humid summers and cold winters. Its annual mean temperature is just above 56°F, and precipitation averages fifty inches per year.

Kentucky's terrain unfolds along a clear east-west gradient, offering striking contrasts across its regions. In the east, the Appalachian Mountains and Cumberland Plateau, characterized by steep slopes and rugged elevations, dominate roughly one-quarter of the state. The Bluegrass Region is known for its gently rolling hills, fertile soil, and extensive karst formations, including sinkholes and caves. These features define the landscape of north-central Kentucky. This region hosts the state's three largest urban areas and serves as an economic and cultural hub. Southward and westward of the Bluegrass Region lies the Pennyroyal, another karst-rich area, while the Western Kentucky Coalfield occupies land adjacent to the Ohio River and is encircled by the Mississippian Plateau. At Kentucky's far western edge lies the Mississippi Embayment, a low-lying extension of the Gulf Coastal Plain that marks the state's transition to the Mississippi River basin. Across these landscapes, surface streams generally flow west or northwest, with major tributaries such as the Licking, Kentucky, Green, Tennessee, and Cumberland Rivers feeding into the Ohio River system.

Kentucky's natural beauty and geographic diversity come with unique natural hazard risks. Severe weather events have become increasingly frequent and destructive, resulting in a troubling trend in disaster occurrence. From 1980 to 1999, the state averaged less than one presidentially declared disaster per year. Since 2000, Kentucky has averaged more than two annual disaster occurrences with recent years seeing even higher numbers, including three in 2024 and five in 2025. These disasters are primarily caused by severe weather conditions: heavy precipitation leading to floods and landslides; high winds including tornadoes and straight-line gusts; damaging winter storms such as ice storms; and episodes of extreme heat. This escalation underscores the vulnerability of Kentucky's communities and infrastructure to climate variability and intensifying weather patterns.

Understanding Kentucky's past, present, and future natural hazards is essential for the effective management of the state's transportation system. This chapter explores natural hazards specific to Kentucky's climate, providing a foundation for assessing environmental challenges and strategies for adaptation in the years ahead.

3.1: NATURAL HAZARDS

3.1.1: FLOODING

Flooding is Kentucky's most common and costly natural hazard, causing an average annual loss of $40 million. With 90,000 miles of rivers and streams, the state is especially prone to flooding. Flooding events can be grouped into two types: (1) regional/riverine flooding and (2) flash flooding.

Flooding can damage pavement and erode embankments essential to the success of the transportation infrastructure system. Furthermore, bridges can be severely impacted by scour[4], and culverts can be damaged and destroyed if their capacity is inadequate for the flows experienced. High water can disrupt transportation system operations and travel, causing mobility and safety concerns.

The spatial patterns of precipitation data illustrate western parts of the Commonwealth experience greater average annual days greater than 3" of precipitation than eastern areas of the state **(Figure 5)**.

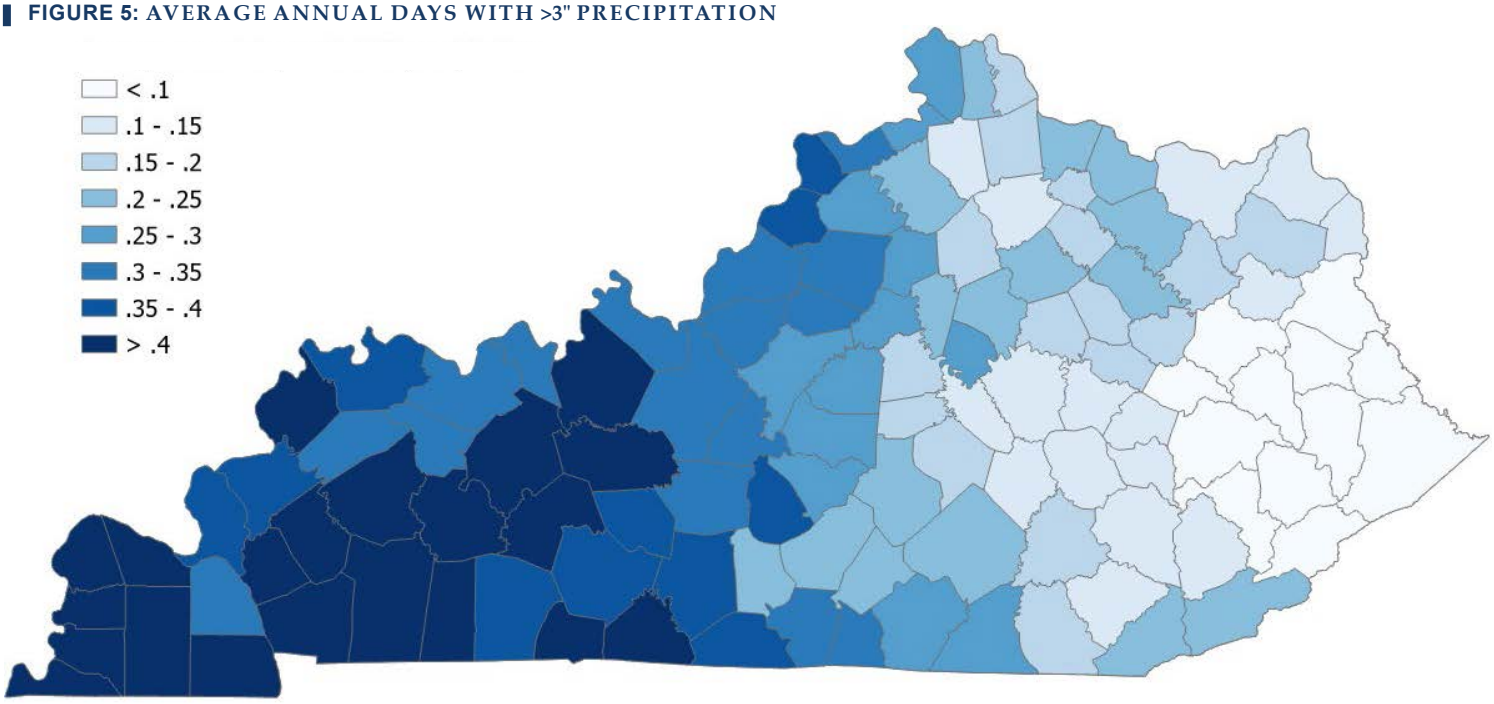
1 REGIONAL OR RIVERINE FLOODING...

Results from heavy, persistent rainfall, sometimes coupled with melting snow. These events saturate the soil and cause excess runoff that can lead to flooding. The nature of riverine flooding can differ depending on the topography. Flooding on the Ohio River and Mississippi River, which encompass large drainage areas across the central United States, tends to occur slowly but tends to be more long lasting. Flooding on upper stretches of the Kentucky River and Licking River tends to occur more quickly and with faster currents, but the duration of the flooding is often shorter.

2 FLASH FLOODING ...

Results from excessive rainfall in a short amount of time, causing water levels to rapidly rise and torrents of water to exceed stream channels. Flash flooding impacts areas across the state but is especially problematic in eastern Kentucky, where rugged terrain funnels water down slopes and into stream channels in valleys or "hollers." Such rapid rises in water levels coupled with swift currents can threaten communities and their infrastructure. Flash flooding can also result from dam failure.

FIGURE 5: AVERAGE ANNUAL DAYS WITH >3" PRECIPITATION



[4] *"Scour occurs when water erodes the sediments that surround the base or support structures for bridges, roads, and other man-made buildings. Scour is often caused by fast-moving water, so scour often occurs during floods." -- U.S. Geological Survey. (n.d.). EarthWord: Scour. U.S. Geological Survey. https://www.usgs.gov/news/science-snippet/earthword-scour*

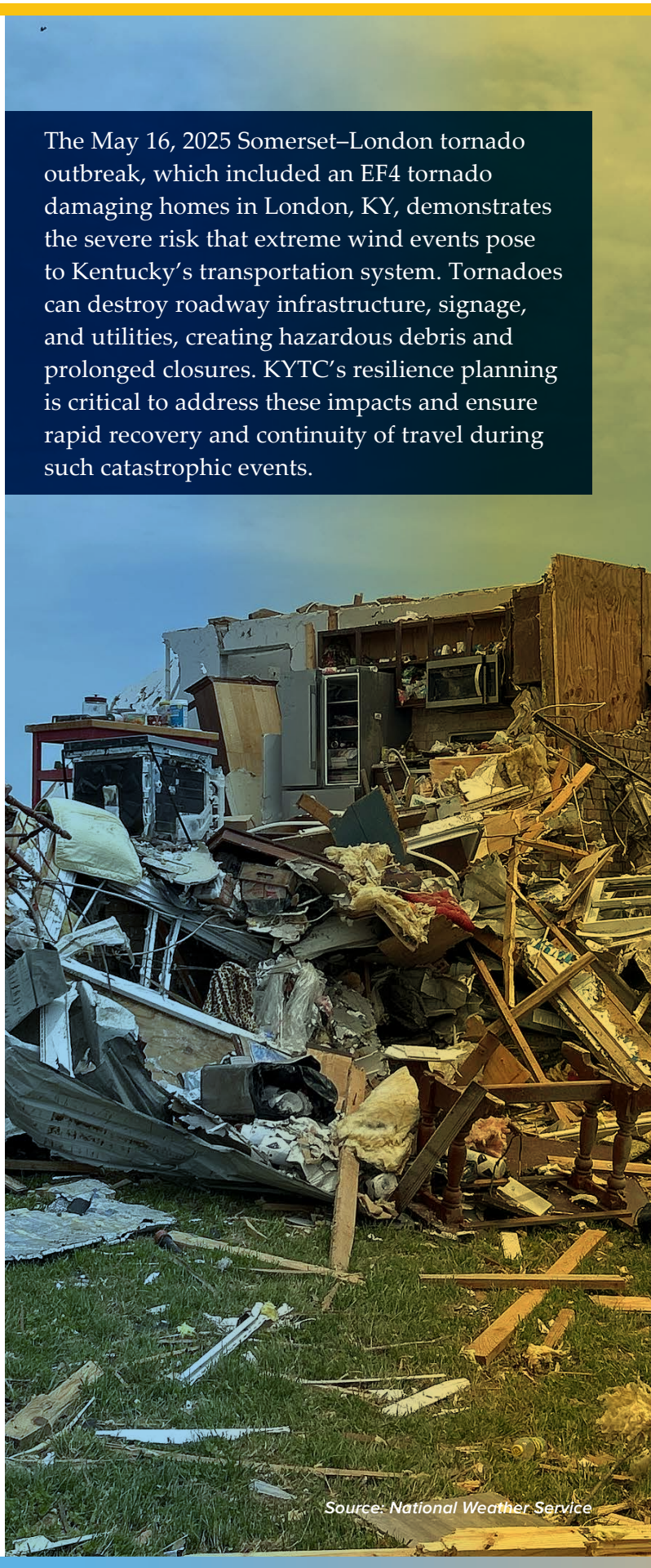
3.1.2: SEVERE STORMS & EXTREME WINDS

Severe storms encompass tornadoes, high winds, and hail experienced through thunderstorms. On average, Kentucky encounters twenty tornadoes per year, the majority of which tend to be of low intensity on the Enhanced Fujita (EF) scale. Since 1950, Kentucky has experienced only one EF5 tornado and 20 EF4 tornadoes, including the long track tornadoes that caused destruction to western Kentucky communities in December 2021 and to Somerset and London in May 2025. Although tornadoes can cause significant damage, their effects on the transportation system are generally minor and short-lived. Damage or destruction of highway signage, lighting, and traffic signals are the most common impacts. Debris in the roadway from structures, utilities, and trees may temporarily disrupt traffic.

Straight-line wind events in Kentucky can occur in conjunction with broader severe weather events. Examples include severe thunderstorms, derechos, or hurricane remnants that have moved inland. Damage to transportation infrastructure from straight-line winds is comparable to that from tornadoes.

Hail is a type of precipitation that occurs with severe thunderstorms where updrafts of air drive precipitation to higher levels of the atmosphere where it cools, freezes, and then falls as ice. While severe hail can damage vehicles, structures, crops, and livestock, public infrastructure damage is generally limited to roadway signage and traffic signals.

The May 16, 2025 Somerset–London tornado outbreak, which included an EF4 tornado damaging homes in London, KY, demonstrates the severe risk that extreme wind events pose to Kentucky's transportation system. Tornadoes can destroy roadway infrastructure, signage, and utilities, creating hazardous debris and prolonged closures. KYTC's resilience planning is critical to address these impacts and ensure rapid recovery and continuity of travel during such catastrophic events.



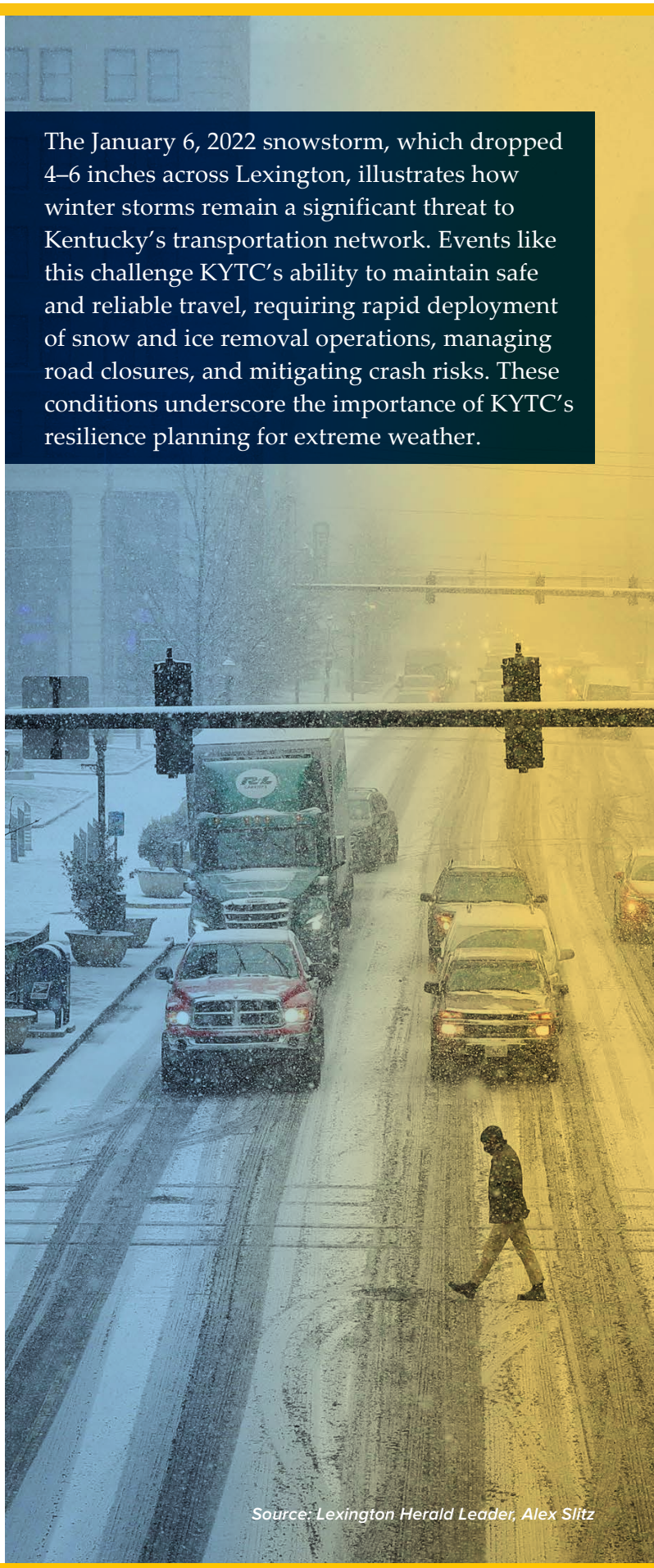
Source: National Weather Service

3.1.3: WINTER STORMS

Extreme winter storms include major snow events, blizzards, and ice storms Winter storms in Kentucky have increased in frequency and intensity since the 1950s and their tracks have shifted northward. Winter storms, especially ice storms, often damage trees because the weight of accumulated ice causes branches to break, creating debris that can block roadways. In addition, icy and snowy conditions pose significant safety hazards for drivers. Blizzards further impede travel. While salt and plowing help maintain mobility, these measures can also contribute to pavement deterioration, though the extent of this impact varies.

The 2009 ice storm is an example of major travel disruptions due to ice. The ice storm caused catastrophic road impacts, leading to widespread closures from ice-covered, impassable roads, and downed trees and power lines. The storm made travel extremely hazardous, requiring National Guard assistance, highlighting it as one of Kentucky's worst natural disasters with huge damage and prolonged power outages.

The January 6, 2022 snowstorm, which dropped 4–6 inches across Lexington, illustrates how winter storms remain a significant threat to Kentucky's transportation network. Events like this challenge KYTC's ability to maintain safe and reliable travel, requiring rapid deployment of snow and ice removal operations, managing road closures, and mitigating crash risks. These conditions underscore the importance of KYTC's resilience planning for extreme weather.



Source: Lexington Herald Leader, Alex Slitz

3.1.4: EXTREME TEMPERATURES

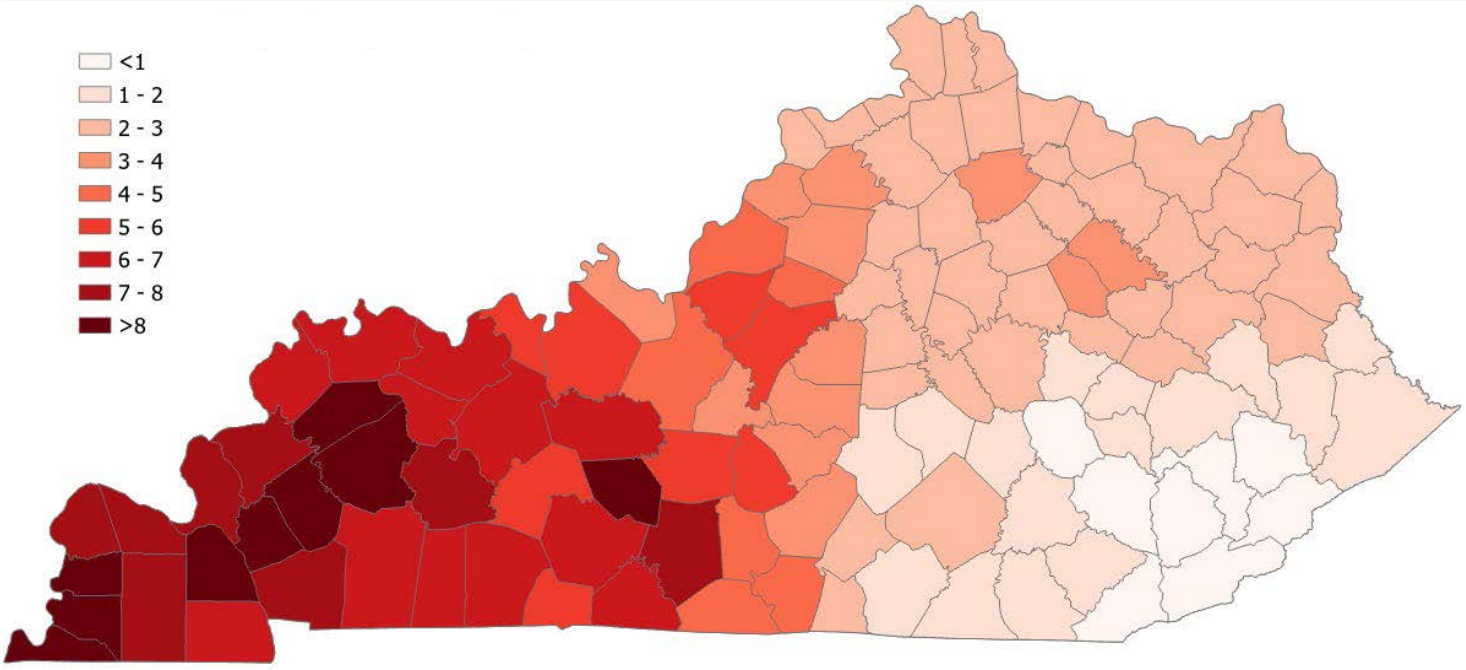
The National Weather Service (NWS) defines extreme heat as temperatures 10˚F or more above the average summer high temperature. In Kentucky, heat advisories and warnings are issued when the forecasted heat index is expected to exceed 105˚F for multiple hours or above 115˚F at any point, or when nighttime lows are forecast to be above 80˚F for consecutive days. On the other hand, extreme cold advisories are issued when the wind chill temperatures are dangerously low, generally around 0°F to -10°F in South Central KY, and -5°F to -15°F in Central/Eastern KY.

Both extreme heat and extreme cold can affect pavement. Pavement can soften and expand when subjected to excessive heat, resulting in damage in the form of rutting or potholes, particularly along heavily trafficked roadways. Extreme cold can lead to pavement cracking and freeze-thaw cycles, which, when combined with moisture, can lead to potholes and other forms of pavement deterioration.

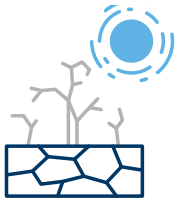
Excessive heat and cold can also place stress on steel bridge joints through thermal expansion and contraction. Extreme heat and cold can also impede agency operations by limiting certain temperature-dependent construction and maintenance activities. Furthermore, extreme temperatures put KYTC employees at risk from frostbite, heat stroke, and other temperature-related illnesses and limit worker productivity.

The spatial patterns of extreme temperatures are similar to the patterns found in the precipitation data. Western parts of the state experience more days where the maximum temperature exceeds 95°F than eastern areas of the state **(Figure 6)**.

FIGURE 6: AVERAGE ANNUAL DAYS WITH TEMPERATURE > 95 DEGREES



Source: KYTC July 2023 Transportation Resilience Improvement Plan



3.1.5: DROUGHT

Drought impacts on the transportation system in Kentucky are rare but possible. Roads built in wetland areas are the most vulnerable to prolonged dry conditions. Extreme drought can cause wetlands to dry out, which changes the soil composition and can degrade the underlying roadbed. Rising temperatures increase evaporation, leading to the decrease in amount of rain that runs off into rivers. Although rainfall during spring is likely to increase, the total amount of water running off into rivers to recharge ground water each year is likely to decrease. As a result, droughts are expected to be more severe and last longer as extreme heat conditions become more frequent and periods without rain become longer.

Severe droughts may also pose challenges for river transportation, which is a core component of Kentucky's economy. The drought of 2005 closed portions of the lower Ohio River to commercial navigation, which delayed shipments of crops and other products between Kentucky and the Mississippi River[5].

In 2012, a drought caused navigation restrictions on the lower Mississippi River, which cost Western Kentucky more than $275 million.

Source: University of Kentucky, Matt Barton

[5] *United States Environmental Protection Agency. (2016, September). What climate change means for Kentucky. Retrieved from https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-ky.pdf*

3.1.6: WILDFIRES

Most wildfires in Kentucky can be attributed to human activity (99%) and are associated with drought conditions, elevated temperatures, and the accumulation of combustible material along a forest floor. Wind also facilitates the spread of fire across the landscape. The eastern region of the state is at the highest risk of wildfire. Wildfire impacts on transportation infrastructure include system delays and significant recovery costs, including for maintenance and damage assessment, road repair, guardrails, signage, electrical supply, culverts, and landscaping.

Wildfire activity in Kentucky is most common in the southeastern part of the state, where steep terrain, dry conditions, and abundant fuels increase ignition risk. Historical USGS records show that from 2002–2015, District 2 experienced only thirteen wildfire events, each minor in scale. Localized incidents highlight that while wildfire outbreaks do occur in western Kentucky, they are typically limited in size, yet still capable of disrupting travel and requiring response along key transportation corridors.

Source: Adobe

3.1.7: SEISMICITY/ EARTHQUAKES

In the eastern half of the U.S., the highest threat for seismic activity is the New Madrid Seismic Zone (NMSZ), which lies near the Mississippi River in Tennessee, Arkansas, Kentucky, Illinois, and Missouri. Specifically, Kentucky's western region lies within the NMSZ influence zone, and its transportation infrastructure—including highways, bridges, and river ports—faces elevated risk. The Mississippi Embayment and surrounding areas are underlain by thick layers of unconsolidated sediments (e.g. sand, silt, and clay) deposited by the Mississippi and Ohio Rivers. These soft, water-saturated soils amplify seismic shaking and are highly susceptible to liquefaction, a process where soil loses strength and behaves like a fluid during intense shaking. Liquefaction can lead to:

- Sand blows and fissures
- Lateral spreading, causing severe damage to roads, bridges, and buried infrastructure.
- Foundation failures and embankment slumping, which threaten highways and levees[6].

Historic earthquakes in the NMSZ have caused uplift and subsidence of large tracts of land, altering river channels and creating oxbow lakes. Future large earthquakes could block or reroute navigation channels; damage levees and flood-control structures, or interrupt barge traffic, with cascading economic impacts on regional and national supply chains.

Developing probabilities for the occurrence of earthquakes in Kentucky is difficult. Some estimates suggest a 25–40% chance of a magnitude 6.0 or greater earthquake in the next 50 years, and up to a 10% chance of a repeat of the severe 1811–1812 earthquake series[7]. These estimates are based on historical seismicity, new information on recurrence of large earthquakes, and the same assumptions that go into the National Seismic Hazard maps. Regardless of the accuracy of probabilities of future earthquakes, planning for seismic resilience is critical to protect mobility and commerce in Kentucky.

[6] *Greenwood, R., & Lee, J. (2015). Strong ground motion inferred from liquefaction features. Bulletin of the Seismological Society of America, 105(5), 2589–2606. https://doi.org/10.1785/0120140345*

[7] *U.S. Geological Survey. (n.d.). New Madrid seismic zone. U.S. Department of the Interior. Retrieved November 17, 2025, from https://www.usgs.gov/programs/earthquake-hazards/new-madrid-seismic-zone*

After a magnitude 3.1 earthquake shook central Kentucky on December 28, 2025, even minor tremors can prompt inspections of roads, bridges, and embankments for cracking, settlement, or slope movement, especially in areas with soft, water-saturated soils. These small but recurring events highlight the need for ongoing seismic preparedness to protect Kentucky's transportation network, particularly in regions influenced by the New Madrid and Wabash Valley seismic zones.

Source: Adobe

3.1.8: LANDSLIDES

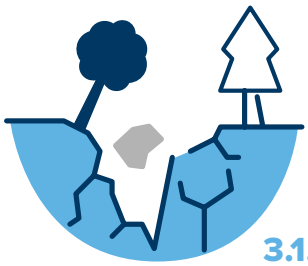
A landslide is defined as the movement of a mass of rock, debris, or earth down a slope. Landslide types include rockslides, rockfalls, topples, flows, and lateral spreads. Because gravity is the fundamental force involved, landslides most frequently occur on steep slopes. Other contributing factors include:

- Erosion by water, such as from rivers, glaciers, or ocean waves, which results in the formation of steep slopes
- Soil saturation from heavy rains or snowmelt
- Seismic activity
- Human activity, such as mining, vegetation removal, placement of man-made structures, or excess weight from the stockpiling of material on a slope

In Kentucky, landslides are most common in the mountains and plateaus of eastern Kentucky, the Outer Bluegrass, the Knobs region, and the Ohio River Valley. Landslides cause impacts to transportation by blocking and, in some cases, damaging roadways and supporting infrastructure. Lane closures, repair, and clean up cause disruption to transportation operations.

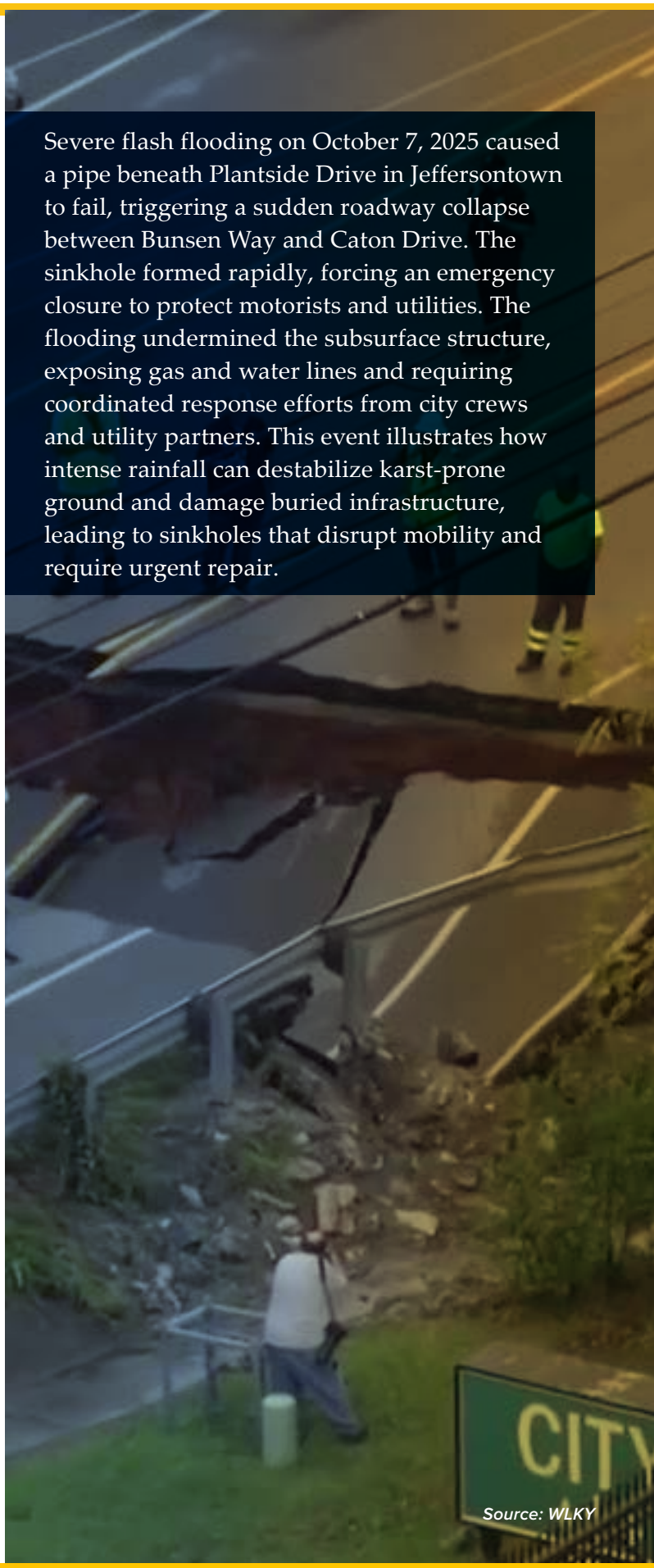
On February 15, 2025, a rockslide along I-69 near the Caldwell–Hopkins County line underscored the ongoing landslide risks affecting Kentucky's transportation network. The slide sent a large mass of rock down a steep slope, covering both northbound lanes and requiring multiple weeks of cleanup before full traffic flow could be restored. KYTC crews worked to clear debris, stabilize the slope, and rebuild shoulder areas, demonstrating how landslides can quickly shut down critical corridors and demand intensive maintenance and recovery efforts.

Source: KYTC



3.1.9: SINKHOLES

Karst topography is associated with sinkholes, caves, sinking streams, and springs. In Kentucky, karst potential is highest in the Inner Bluegrass Region, the Western Pennyroyal region, and the Eastern Pennyroyal region. Kentucky is fifth in the nation in terms of impact from sinkholes. Estimates indicate that 55% of the land in the state has the potential for karst development. Additionally, 38% of the state has enough karst development to be recognized topographically, and 25% has well-developed karst features[8]. Sinkholes and karst formation can impact roadway infrastructure by causing the collapse of roadway surfaces, ditch lines, and bridge foundations.



Severe flash flooding on October 7, 2025 caused a pipe beneath Plantside Drive in Jeffersontown to fail, triggering a sudden roadway collapse between Bunsen Way and Caton Drive. The sinkhole formed rapidly, forcing an emergency closure to protect motorists and utilities. The flooding undermined the subsurface structure, exposing gas and water lines and requiring coordinated response efforts from city crews and utility partners. This event illustrates how intense rainfall can destabilize karst-prone ground and damage buried infrastructure, leading to sinkholes that disrupt mobility and require urgent repair.

Source: WLKY

[8] *Currens, James C., "Kentucky is Karst Country! What You Should Know About Sinkholes and Springs" (2002). Information Circular--KGS. 4. https://uknowledge.uky.edu/kgs_ic/4*

3.2: CLIMATE PROJECTIONS

Climate projections offer a window into the future, helping us understand how weather patterns may shift over time. For transportation planners and engineers, this information is critical—it guides decisions on how to protect roads, bridges, and other infrastructure from extreme weather events that are expected to become more frequent and severe.

The Fourth National Climate Assessment (NCA4), published in 2018, includes Kentucky in the Southeast region and projects significant changes throughout the 21st century.

The NCA4 findings indicate that Kentucky is expected to see an overall increase in annual precipitation.

- Winter and spring are projected to experience the greatest increases.
- Summer, however, may see a decline in rainfall.
- Additionally, projections suggest a higher likelihood of heavy precipitation events.

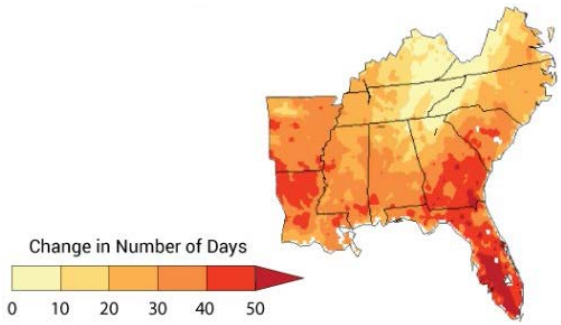
These changes could lead to more frequent and severe flooding, while also heightening the risk of extreme heat and drought during the summer months.

TEMPERATURE TRENDS

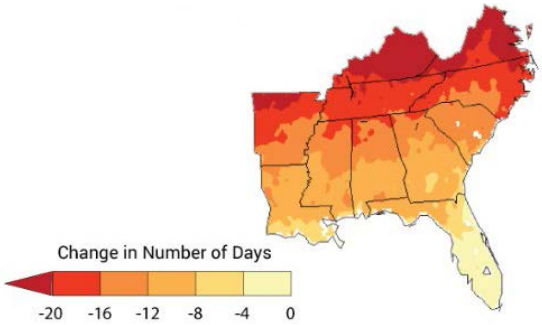
MILDER WINTERS:
Cold days will become less common.

HOTTER SUMMERS:
Extremely hot days will occur more often.

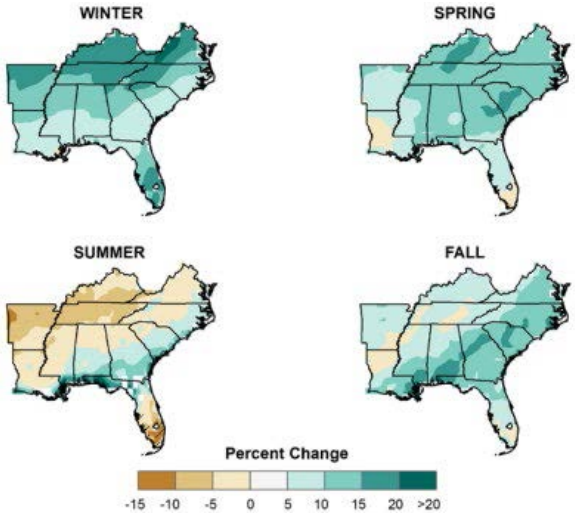
PROLONGED HEAT & DROUGHT:
Higher summer temperatures could lead to extended heat waves and longer dry spells.



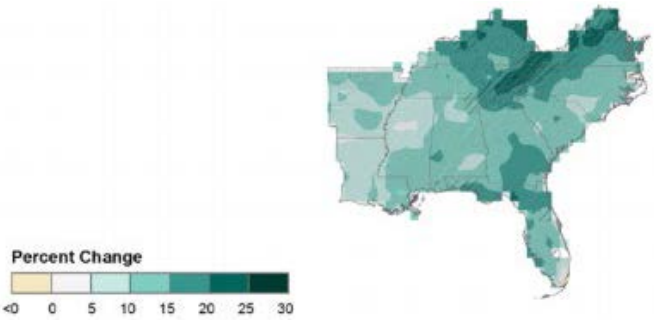
Simulated difference in the mean annual number of days with a maximum temperature greater than 95°F for the Southeast region for the2041-2070 period with respect to the reference period of 1920-2000. Source: NCA4.



Simulated difference in the mean annual number of days with a minimum temperature lower than 32°F for the Southeast region for the 2041-2070 period with respect to the reference period of 1920-2000. Source: NCA4.



Simulated difference in annual and seasonal mean precipitation for the Southeast region for 2041-2070 with respect to the reference period of 1971-2000. Source: NCA4.



Simulated percentage difference in the mean annual number of days with precipitation of greater than one inch for the Southeast region for the 2041-2070 period with respect to the reference period of 1980-2000. Source: NCA4.

3.3: RISK-BASED VULNERABILITY ASSESSMENT

3.3.1: OVERVIEW OF PAST ASSESSMENTS

TRANSPORTATION SYSTEM VULNERABILITY AND RESILIENCE TO EXTREME WEATHER EVENTS AND OTHER NATURAL HAZARDS, PILOT PROJECT

KYTC DISTRICT 1 (2016)

This study provided an initial framework for vulnerability assessments and documented natural hazards likely to affect Kentucky's NHS in the future. The study culminated in a vulnerability assessment of the NHS in District 1 (Western Kentucky).

The study integrated meteorological and asset data analysis with district-level workshops, leveraging local expertise to capture firsthand insights on highway disruptions caused by natural hazards.

KEY FINDINGS/PRODUCTS FROM THE STUDY WERE:

- Climate projections for temperature and precipitation in Kentucky
- Identification of major hazards: earthquakes, flooding, landslides, and sinkholes
- Significant NHS assets and miles at risk under varying hazard intensities
- Demonstrated the value of vulnerability assessments for proactive planning

TRANSPORTATION SYSTEM VULNERABILITY AND RESILIENCE TO EXTREME WEATHER EVENTS AND OTHER NATURAL HAZARDS - FINAL RESULTS OF VULNERABILITY ASSESSMENT OF NATIONAL HIGHWAY SYSTEM

ALL KYTC DISTRICTS (2018)

Building on the pilot in District 1, in 2016, KYTC and KTC completed a risk-based vulnerability assessment of the state's transportation system to extreme weather and natural hazards. This effort was driven by federal legislation and guidance from FHWA, which directed states to identify infrastructure vulnerabilities, develop risk-based asset management plans, and integrate findings into planning, design, and maintenance practices.

The assessment focused on Kentucky's NHS and four major hazards: earthquakes, floods, landslides, and sinkholes (the same as those considered in the pilot study). Assets such as highway segments, bridges, culverts, and overpasses were evaluated using a modified version of FHWA's Vulnerability Assessment Scoring Tool (VAST), which assigns vulnerability scores for each segment and hazard type.

Similar to the pilot, overlays of hazard data from a desktop analysis were combined with workshop-based inputs on exposure, asset criticality, and the anticipated severity of impacts to identify potential vulnerabilities to these hazards of NHS road segments, bridges, large culverts, and structures (overpasses).

To conduct the vulnerability assessment, KYTC used a hybrid approach with three key components:

- **Data Analysis:** Gathering and analyzing available data on transportation assets and natural hazards.
- **Local Expertise:** Hosting district-level workshops to capture insights from local experts on asset vulnerabilities.
- **Integrated Assessment:** Combining all data and workshop findings into a comprehensive evaluation.

The results of this statewide vulnerability assessment provided a high-level overview of potential NHS disruptions due to natural hazards. Of the 287 NHS segments studied statewide, 83 were expected to be highly vulnerable to either earthquakes, floods, landslides, or sinkholes. Of these segments, 13 had high vulnerability to two hazard types and one additional segment had high vulnerability to three hazard types. In addition to the identification of vulnerabilities, the study asked participants to describe the worst-case hazard scenario for the district in terms of disruption to the NHS. In some cases, the identified scenario was a type of hazard (e.g., major earthquake) while in other cases the scenario was specific to a particular asset (e.g., flood/landslide closing of the Mountain Parkway in District 10). It was emphasized that the information generated by the study would assist decision-makers in proactively addressing challenges prior to them becoming severe.

3.3.2: HOW THE RISK ASSESSMENT WAS STRUCTURED (METHODOLOGY)

To guide the vulnerability assessment, KYTC and KTC developed a risk matrix **(Table 1)** that considered two factors for each hazard type across the 12 districts:

RISK MATRIX SNAPSHOT

RISK MATRIX CONSIDERATION FACTORS:

- **Likelihood:** How often an event might occur.
- **Severity:** The potential consequence if it does occur.

TABLE 1: RISK MATRIX

Severity	Likelihood				
	1	2	3	4	5
A	1A	2A	3A	4A	5A
B	1B	2B	3B	4B	5B
C	1C	2C	3C	4C	5C
D	1D	2D	3D	4D	5D
E	1E	2E	3E	4E	5E

HIGHER LIKELIHOOD + **HIGHER** SEVERITY = **HIGHER** RISK

LIKELIHOOD DEFINED ON A SCALE OF 1-5:

1. VERY LIKELY: Occurs repeatedly to assets across a wide area.

2. LIKELY: Occurs more than once to multiple assets.

3. MEDIUM: May occur once to some assets.

4. UNLIKELY: May occur once to a few assets in a limited area.

5. VERY UNLIKELY: Unlikely to occur.

SEVERITY DEFINED ON A SCALE OF A-E:

A. CATASTROPHIC: Huge financial losses; permanent damage and/or long-term loss of service across a sizeable region; long-term impact on commercial revenue.

B. MAJOR: Major financial losses; some long-term impacts on services; infrastructure damage requiring extensive repair.

C. MODERATE: High financial losses for multiple owners; disruption of services for several days; widespread infrastructure damage requiring maintenance and repair.

D. MINOR: Moderate financial losses for small number of owners; disruption of services for a day or two; localized infrastructure damage.

E. INSIGNIFICANT: No infrastructure damage; minimal financial losses; short-term inconvenience.

Combining these two factors produced an overall risk score, where higher likelihood and severity resulted in higher risk (shown in darker shades of red on maps), while lower likelihood and severity resulted in lower risk (lighter shades of red).

3.3.3: DISTRICT-LEVEL FINDINGS

Workshops with KYTC personnel in each district provided qualitative input. Participants reviewed hazard maps and rated highway segments based on two criteria:

- Vulnerability to natural hazards
- Criticality to the overall highway system

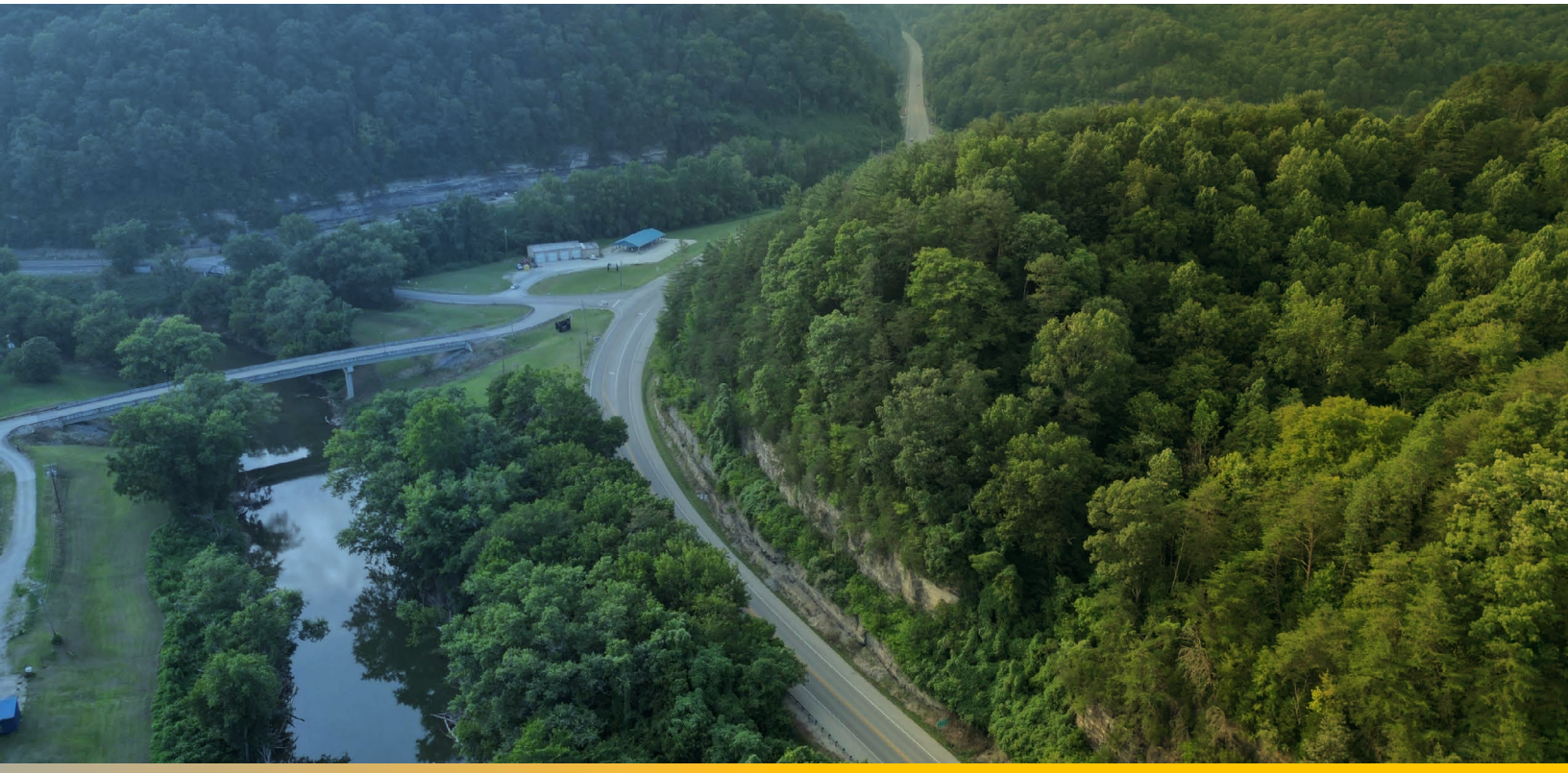
Table 2 shows the results of this assessment for each of KYTC's 12 districts:

The district-level assessment captured both the likelihood of future hazards and their potential severity:

- **Flooding:** High risk in all 12 KYTC districts; greatest in mountainous districts (10, 11, and 12)
- **Landslides:** High risk in mountainous districts and District 6
- **Sinkholes:** Highest risk in Districts 3 and 4 (karst landscapes)

TABLE 2: RISK SCORE RESULTS

KYTC District	Flood	Wind/ Severe Storms	Drought	Dam Failure	Wildfire	Landslide	Heat	Earthquake	Sinkhole
District 1	2C	1D	3E	5A	4D	3C	1D	4A	3D
District 2	2C	1D	3E	5A	4D	3D	1D	4B	2C
District 3	2C	1D	3E	5A	4D	3D	1D	4C	1B
District 4	2C	1D	3E	5A	4D	3C	1D	5C	1B
District 5	2C	1D	3E	5A	4D	4D	1D	5D	2C
District 6	2C	2D	3E	5A	4D	2B	2D	5E	4D
District 7	3C	2D	3E	5A	4D	4D	2D	5E	3C
District 8	2C	2D	3E	5A	3D	2C	2D	5E	3C
District 9	2B	2D	3E	5A	3D	2B	3D	5E	4D
District 10	2A	3D	3E	5A	3D	1B	3D	5E	4D
District 11	2A	3D	3E	5A	3D	1B	3D	4D	4D
District 12	2A	3D	3E	5A	3D	1B	3D	5D	4D



3.3.4: ASSET-LEVEL ASSESSMENT

In addition to the district-level analysis, KYTC and KTC assessed NHS assets, including highways, bridges, culverts, and other structures, against the four major hazards: earthquakes, floods, landslides, and sinkholes. This spatial analysis (with GIS) compiled roadway and hazard data to identify segments vulnerable to each of the respective hazards according to the indicator data, which is further described in this section. **Table 3** summarizes the relationship between these NHS assets statewide and selected hazard indicators.

To incorporate all the varying data types, FHWA's *Vulnerability Assessment Scoring Tool* (VAST) was used. This allowed the project team to combine quantitative data gathered from available sources with data generated in the workshops. VAST was used for this project to incorporate multiple and varying datasets pertaining to natural hazard risk and asset criticality. In all, 22 indicator datasets were included for the hazards of earthquake, flooding, landslides, and sinkholes and their relation to Kentucky's NHS.

INDICATOR DATA EXPLAINED:

- **Seismic hazard:** Is defined according to maximum Peak Ground Accel (PGA) with a 2% likelihood of exceedance in 50 years. Exposure to seismic hazards utilizes the U.S. Geological Survey's National Seismic Hazard Model, which accounts for both the frequency and magnitude of seismic activity.
- **Flood vulnerability:** Is identified according to the Federal Emergency Management Agency's (FEMA) Flood Insurance Rate Maps (FIRM). The FIRM includes digital flood mapping of the 100-year flood event. The 100-year flood event is a flood with an approximately 1% chance of occurring in any given year. The 100-year flood map indicates areas that would be inundated if such a flood were to occur.
- **Sinkhole vulnerability:** Is identified according to the Kentucky Geological Survey's (KGS) mapping of karst potential in the Commonwealth. Areas of high karst potential are vulnerable to sinkhole formation. Similarly, landslide vulnerability is identified according to KGS' mapping of statewide landslide potential.

TABLE 3: ASSET-LEVEL ASSESSMENT

Asset Type	KYTC Total	PGA* ≥ 60	PGA ≥ 30 and < 60	PGA ≥ 18 and < 30	100-yr Flood Plain	Major Karst Potential	Moderate Karst Potential	High Landslide Potential	Moderate Landslide Potential
Total NHS Road Miles:**	6,151	194	425	771	229	1,921	848	1,372	401
Interstate:	2,064	31	161	241	Y49	762	398	290	56
Parkway:	1,034	60	61	218	33	209	174	59	77
US Highway:	1,932	101	128	295	97	694	136	613	181
KY Routes:	1,076	2	76	17	49	227	141	409	86
Local Routes:	44	0	0	0	0	29	0	0	0
Bridges:**	772	51	93	143	431	149	46	231	67
Culverts:	292	12	21	21	166	86	40	75	27
Structures	1,409	56	109	178	26	462	188	205	86

Maximum PGA with 2% likelihood of exceedance in 50 years. Centerline miles. ***Includes only those listed in the National Bridge Inventory database.*

3.3.5: KEY RESULTS

Figure 7 identifies the VAST results of NHS vulnerability to each of these four hazards.

The VAST results highlight areas where policy changes or infrastructure improvements can strengthen resilience of vulnerable transportation assets. By acting on these findings, KYTC can:

- Prevent major incidents and closures
- Identify and resolve issues before they grow unmanageable
- Reduce financial losses
- Maintain a safe, reliable transportation system
- Avoid negative impacts on commerce and public confidence

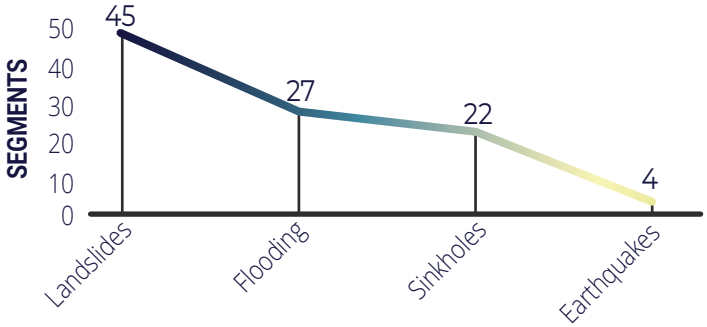
OF THE 287 NHS SEGMENTS IN THIS ASSESSMENT:

83 NHS SEGMENTS
ARE HIGHLY VULNERABLE TO **ONE OR MORE** HAZARD TYPES

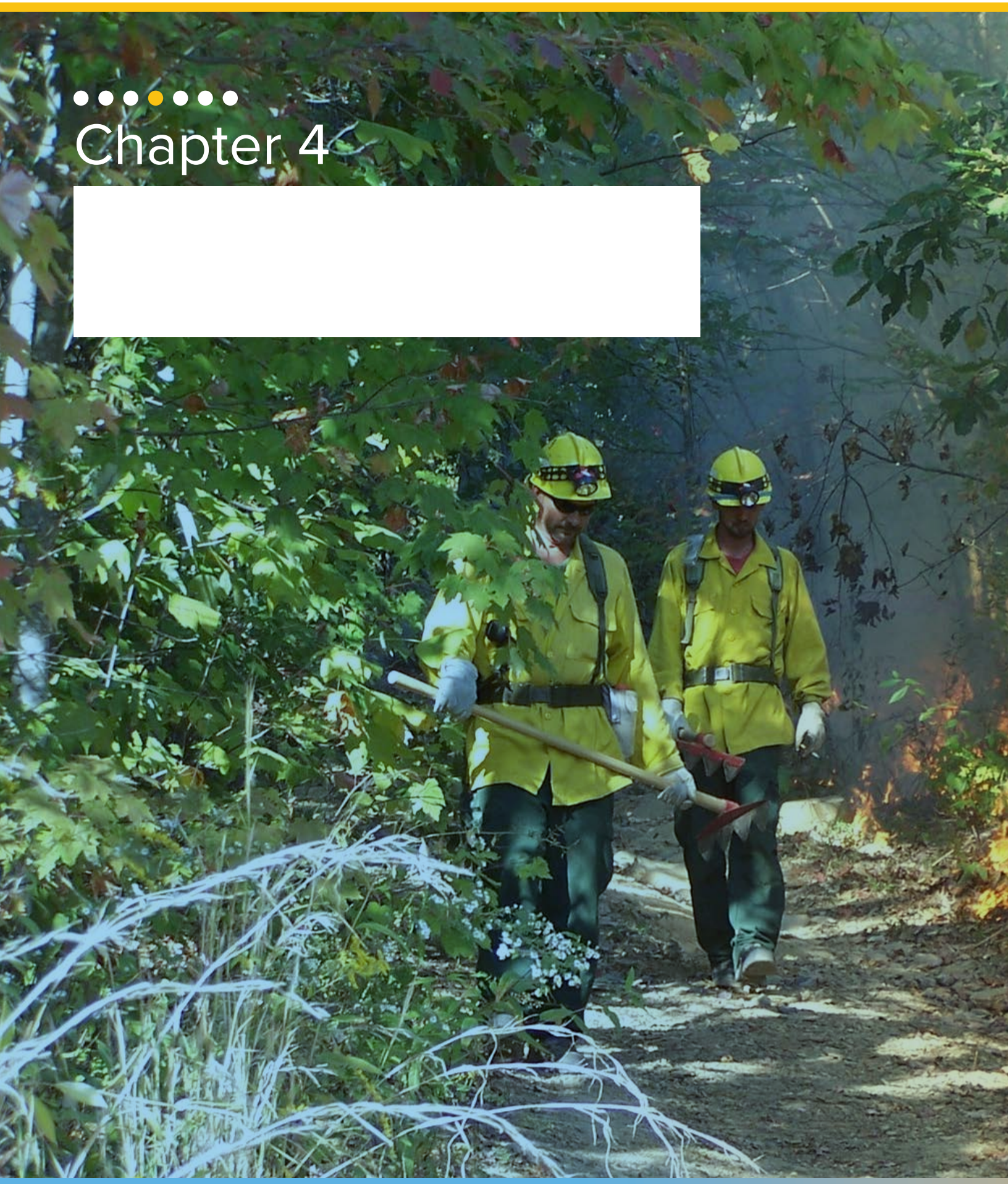
13 NHS SEGMENTS
ARE HIGHLY VULNERABLE TO **TWO** HAZARD TYPES

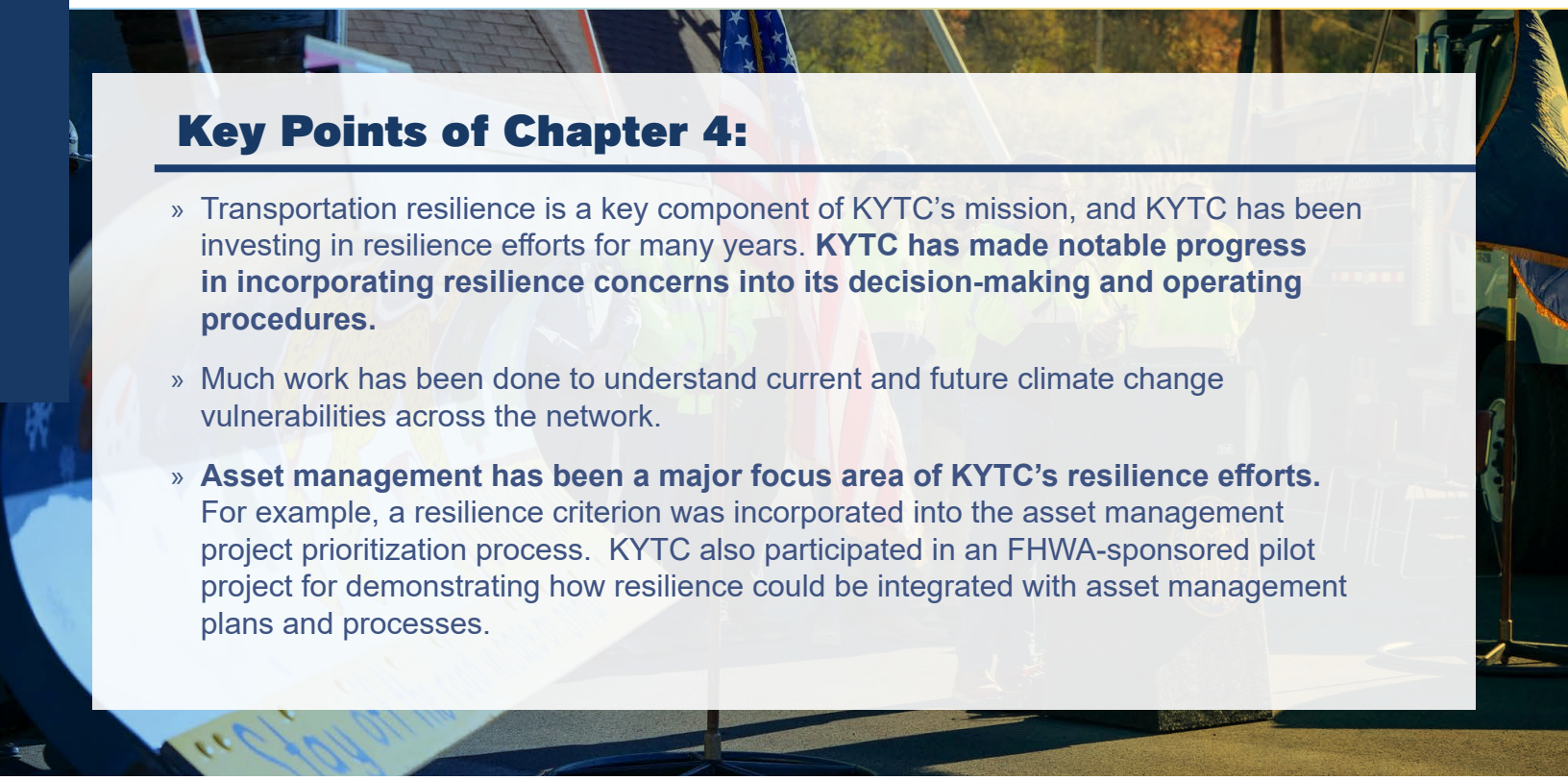
1 NHS SEGMENT
IS HIGHLY VULNERABLE TO **THREE** HAZARD TYPES

FIGURE 7: BREAKDOWN BY HAZARD



Chapter 4





Key Points of Chapter 4:

- Transportation resilience is a key component of KYTC's mission, and KYTC has been investing in resilience efforts for many years. **KYTC has made notable progress in incorporating resilience concerns into its decision-making and operating procedures.**
- Much work has been done to understand current and future climate change vulnerabilities across the network.
- **Asset management has been a major focus area of KYTC's resilience efforts.** For example, a resilience criterion was incorporated into the asset management project prioritization process. KYTC also participated in an FHWA-sponsored pilot project for demonstrating how resilience could be integrated with asset management plans and processes.

Resilience is not a new concept to KYTC. The Cabinet has taken many actions to improve the resilience of the Commonwealth's highway network to natural hazard events throughout the last decade. KYTC is committed to preparing the agency and its staff for providing the citizens of Kentucky with the most cost-effective and efficient response when disasters affect the Commonwealth's transportation system.

This section details some of KYTC's initiatives, organized around the four phases of emergency management: mitigate, prepare, respond, and recover **(Figure 8)**. The four phases of emergency management form a cycle that is connected to the concept of resilience.

THE FOUR PHASES OF EMERGENCY MANAGEMENT EXPLAINED:

- **Mitigation:** Long-term resilience is strengthened through proactively addressing vulnerabilities and minimizing potential damage.
- **Preparedness:** Preparedness builds capacity to respond effectively to disasters.
- **Response:** Resilient systems and procedures facilitate a well-coordinated response that limits the impacts of disasters and ensures continuity of critical services.
- **Recovery:** A resilient recovery improves affected infrastructure systems to better withstand future events.

FIGURE 8: FOUR PHASES OF EMERGENCY MANAGEMENT AS IT RELATES TO RESILIENCE

ROAD ACCESS TO HIGH-GROUND HOUSING SITE

At Chestnut Ridge, KYTC awarded a $2 million contract for the first phase of a project to develop and construct a half-mile access road to the housing site. Storm pipe installations, the addition of sidewalks and curbs, and asphalt paving operations will follow in phase two. This first phase of the road project should be completed in the fall of 2026.

Source: KYTC

4.1: MITIGATE

KYTC works to identify potential vulnerabilities early and take steps to reduce risks before they become problems. By incorporating mitigation strategies into project scoping, design, and programming, KYTC aims to minimize damage, protect critical assets, and ensure transportation systems remain reliable over the long term.

4.1.1: PROJECT SCOPING AND DESIGN

KYTC currently does the following activities as it relates to project scoping and design:

- Examines earthquake retrofits of bridges in western Kentucky.
- Incorporates flood risk enhancements into the design of the Mountain Parkway Project.
- Considers access to hospitals and major freight generators as part of project planning (with possible extension to airport access in the future given their role in disaster recovery).
- Examines potential geohazard locations in advance to identify potential landslide locations prior to a project being forwarded to project development.
- Assesses the condition and performance of culverts during the project design process for their capacity to handle future hazards (design exceptions occur when it is determined that the context and experience warrant design criteria more robust than current KYTC standards).

4.1.2: PROJECT PROGRAMMING

STRATEGIC HIGHWAY INVESTMENT FORMULA FOR TOMORROW

The Strategic Highway Investment Formula for Tomorrow (SHIFT) is KYTC's framework for prioritizing capital improvement projects within the constraints of limited transportation funding. This process is critical because it determines which projects advance for funding consideration in the Highway Plan. Resilience is integrated into the process by including "roadway criticality" and "detour availability" when prioritizing investment projects.

Through the SHIFT framework, projects are evaluated using a data-driven scoring system based on seven key attributes. By applying these criteria, SHIFT ensures that funding decisions are transparent, objective, and aligned with Kentucky's transportation priorities.

ASSET MANAGEMENT PLANNING

Asset management planning is central to building a resilient transportation system and has been a major focus area of KYTC's resilience efforts. Beyond maintenance, asset management is about proactively protecting investments from future environmental risks and ensuring long-term system performance.

KYTC maintains a comprehensive database of detailed records for both federal-aid routes and local/rural secondary roads. This system supports eligibility for reimbursement through FHWA's Emergency Relief (ER) program and FEMA's Public Assistance program.

Asset management planning ensures that each asset's lifecycle, from initial construction through maintenance, repair, and eventual replacement, is fully documented and evaluated for resilience and cost-effectiveness. Where available, KYTC's asset management system integrates estimated maintenance and upgrade costs, projected service life, and vulnerability to natural hazards.

As of 2022, the database tracks thousands of assets statewide, with total estimated replacement and repair costs exceeding $1 billion. This data enables KYTC to identify trends in asset deterioration, prioritize investments, and monitor cost changes over time, particularly in response to the growing frequency and severity of extreme weather events.

THE SHIFT FRAMEWORK SEVEN KEY ATTRIBUTES:

- Asset management
- Benefit/cost ratio
- Congestion
- Economic growth
- Non-motorized mobility
- Resiliency
- Safety

EXTREME TEMPERATURES

KYTC has taken a holistic approach to build a more resilient pavement network for its citizens. Extreme temperature (high and low) constitutes an environmental risk that can impact the resilience of KYTC's pavement systems.

Some of the main pavement vulnerabilities to extreme high temperatures include:

- Increased rutting of asphalt
- Increased curling and warping stresses in concrete pavements that can result in more blow-ups during the summer months

For the key risks and vulnerabilities identified for pavements, KYTC considers a range of adaptation strategies that can be implemented at various stages of the pavement life cycle. These strategies include adaptation to:

- Material selection. KYTC is routinely evaluating potential issues such as suitability of asphalt binder grades based on temperature gradient trends across the Commonwealth.
- KYTC conducts additional structural testing on its pavement network to determine appropriate future treatment needs based on structural capacity.

The TAMP outlines KYTC's life cycle planning (LCP) efforts to maximize pavement performance. The LCP analysis demonstrates the benefits associated with the increased use of preventive maintenance, and other low-cost treatments to manage KYTC's road network. Based on the results of this analysis, KYTC is continuing its pavement strategy that seeks to optimize the use of preventive maintenance on all networks: Interstate, Parkways, and Mountain Parkway (MP) roads. Under this strategy the proactive application of preservation treatments is used to delay the progression of deterioration and the need for overlays or other major rehabilitation actions. Treatments are prioritized by traffic volume to support KYTC's efforts to achieve its pavement condition goals and targets.

In 2018, KTC/KYTC completed a FHWA pilot project on Extreme Weather, Proxy Indicators, and Asset Management. As part of the project, the research team investigated the viability of using climate projection data to model future pavement performance. The study utilized the Mechanistic Empirical Pavement Design software (Pavement ME) to model performance for two 20-year periods (2020-2039, and 2040-2059). Climate projection data were obtained from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model dataset.

Pavement performance was predicted for both a 20-year and 40-year anticipated pavement life. In each of the pavement design projections, Pavement ME results demonstrated increased pavement distress levels associated with asphalt surface rutting and wheel path fatigue cracking. The predicted distresses, however, were within the normal variation of the existing stations across the state. As a result, the increases were not high enough to warrant altering pavement design to withstand such hotter conditions.

PRECIPITATION

In terms of precipitation, the main environmental risks that impact the resilience of KYTC's pavement systems include:

- Higher average precipitation levels
- More extreme rainfall events
- Increasing number of flooding events

These precipitation-involved risks lead to vulnerabilities including the following:

- Reduced pavement structural capacity of unbound base layers and subgrade due to increased precipitation and flooding
- Reduced surface friction due to more extreme rainfall events

KYTC considers a range of adaptation strategies that can be implemented at various stages of the pavement life cycle. These strategies include adaptions to:

- Construction procedures: KYTC is improving the quality of pavement construction by placing increased emphasis on construction inspection, acceptance, and project delivery.
- Maintenance and operations activities: KYTC has increased efforts to seal cracks and joints in existing pavements and is currently investigating the use of asphalt pavement preservation techniques (e.g., chip seals, fog seals, microsurfacing) that are more effective in reducing permeability.
- Design approaches: KYTC is conducting research with the Kentucky Transportation Center and the National Center for Asphalt Technology to design asphalt mixtures for terminal friction levels. The research will optimize asphalt mix designs that enable the consideration of friction over the service life of the asphalt pavement surface layer.
- Project prioritization: KYTC is in the process of enhancing the asset management pavement project selection to include the system friction data set as well as mobility and condition considerations.

Source: KYTC

STATEWIDE BRIDGE PROGRAM

KYTC has implemented a statewide bridge program for Asset Management and Replacement projects. Planning activities proceed in three steps:

- The Central Office Bridge Maintenance Department develops an optimized list which includes cost estimates. This work is now done primarily using the Bridge Management System (BMS). Prioritization of bridge projects includes a risk index which considers resiliency related factors such as scour and vulnerability.
- The Central Office integrates required programs from existing policies and directives, such as 3-ton metal culverts, timber piles, reinforced concrete deck girders, border bridges, and the I-65 rehabilitation.
- Districts submit their recommendations, which pick up needs based on local knowledge and maintenance activities.

The products of these steps are combined and constrained by the allocated budget, then undergo final checks, to ensure that the Six-Year Plan:

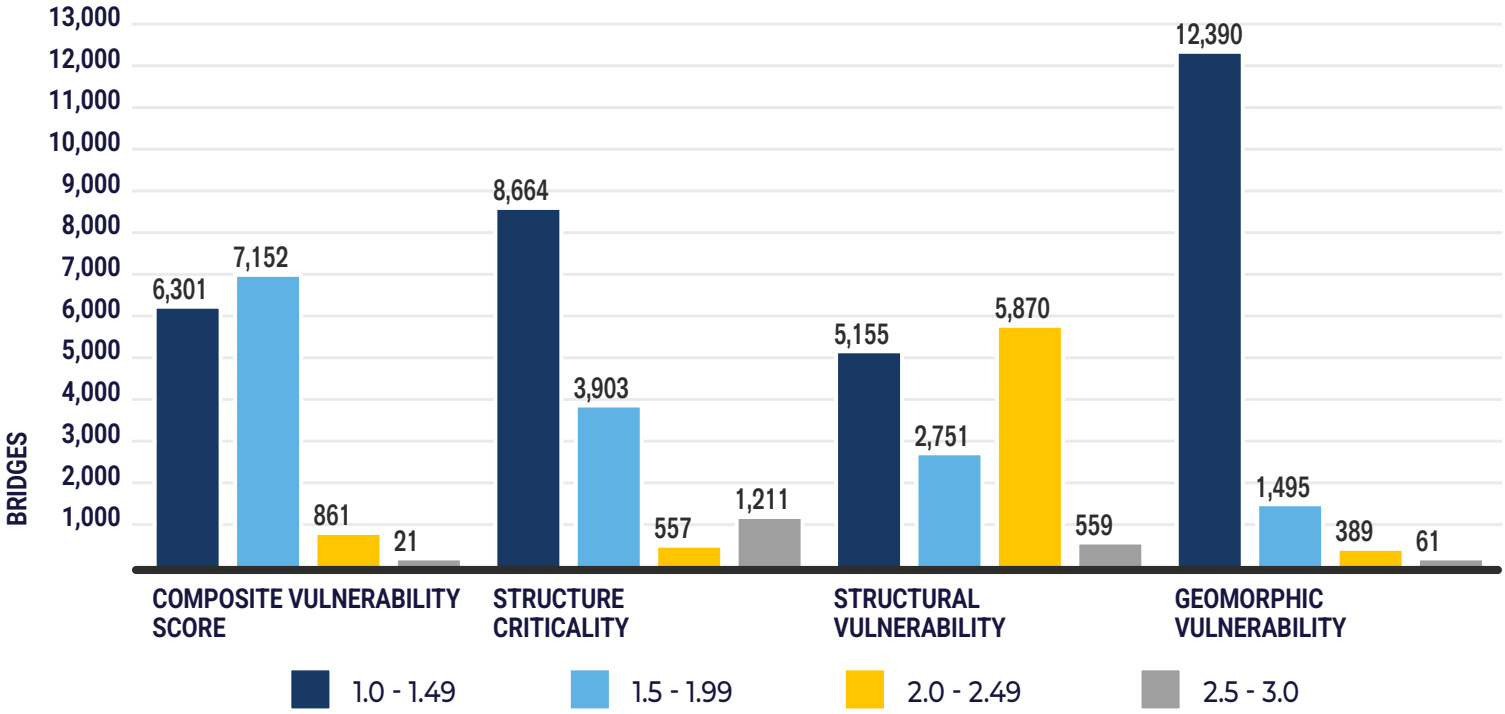
- Is risk based (highest risk structures are included),
- Is equitable among districts,
- Targets Fair bridges (as well as Poor), in line with the TAMP, to guard against falling back to a worst-first process.

Based on the results from the LCP analysis, the KYTC strategy creates a balanced approach to Asset Management and bridge replacement projects. The analysis recognizes that the worst-first approach, which focuses on replacement of bridges when they deteriorate into Poor condition, will leave less money for preservation of bridges in Good and Fair conditions. This, in turn, will yield ineffective results leading to more costly repairs or replacements in the future. KYTC avoids this by using its asset management program to target Fair-condition bridges where strategic preservation and rehabilitation can restore good condition or keep them well away from the Poor category.

KYTC utilizes four different types of projects as part of its bridge management practice, all aimed at keeping the condition of its bridge inventory in a state of good repair and within the national and state-specific performance criteria. The recommended bridge life cycle management strategy addresses a balanced program of preventive maintenance, rehabilitation, functional improvement, and replacement, as explained below.

- Preservation of Bridges in Fair and Good Condition
  - Cyclical preventive maintenance based on a preset schedule of activities, or preset intervals.
  - Condition-based preservation and spot repairs, when deteriorated elements are found on bridges that are otherwise rated Good or can be restored to Good.

FIGURE 9: BRIDGE VULNERABILITY SCORING INDICES



- The life cycle management strategy includes the following preservation activities:
  - Resealing and repairing of joints.
  - Cleaning and sealing of bearings.
  - Bridge washing and cleaning (including deck, super- and substructure).
  - Sealing of decks.
  - Painting of steel members.
  - Patching and/or overlays of bridge decks.
  - Cleaning and painting of pier caps and abutments.
  - Addressing stream channel risks (e.g., scour, drift, sediment, and bank stabilization).
- Rehabilitations of Bridges in Fair Condition.
- Major Rehabilitation or Replacements of Bridges in Poor Condition.
- Bridge Functional Improvements. KYTC is planning to gradually address functional improvements at the network level on:
  - Bridges having deficiencies in their geometry, clearances, foundations, or condition which restrict the flow of traffic, or which increase the risk of service disruption from extreme weather events.
  - Bridges with a weight limit less than that of the approach roadway.

This balanced program, incorporated into KYTC's holistic bridge preservation program over time in a systematic manner, will require sufficient funding levels backed by implementation of appropriate guidance, specifications, and practices at the Commonwealth level, practiced by the central office and district offices.

As part of the 2018 FHWA pilot project on Extreme Weather, Proxy Indicators, and Asset Management, a bridge vulnerability rating methodology was developed that incorporated KYTC bridge evaluation data. The methodology produced bridge ratings for Geomorphic Vulnerability, Structural Vulnerability, and Structure Criticality. These scores were then combined to produce a Bridge Composite Vulnerability score **(Figure 9)**. The index is used as a supplement to the BMS and the asset management bridge project selection to ensure that all relevant goals and objectives, particularly safety and mobility, are appropriately considered in programming decisions.

4.1.3: RESEARCH & STUDIES

KTC RESEARCH

KYTC is conducting numerous research studies with KTC that are providing new tools, procedures, and strategies for enhancing the resilience of the transportation system. For example, KTC is leading ongoing research efforts to better understand the projected impacts of extreme weather on Kentucky's transportation infrastructure. This research integrates historical damage records from KYTC's emergency repair database with daily precipitation and temperature data to develop probabilistic models that estimate future hazard likelihoods and consequences. These models are designed to support long-range planning and identifying asset classes most vulnerable to climate stressors. Within this framework, bridges and culverts are being evaluated for flood sensitivity using a screening tool that combines National Bridge Inventory (NBI) metrics with geomorphic and structural data. This tool enables KYTC to rank assets by vulnerability without requiring extensive fieldwork, making it a cost-effective method for resilience planning.

KTC's research also explores the use of Representative Concentration Pathway (RCP) scenarios to assess future temperature, and precipitation trends. These projections are being applied to pavement design methodologies using Pavement ME software. A case study in Bowling Green demonstrated that predicted climate impacts were within the range of normal variation, suggesting that existing design procedures remain valid in some areas. However, the research also highlights the need for updated standards in regions where extreme weather may significantly alter asset performance.

Although the modeling effort is ongoing, preliminary results suggest that these tools can be used to forecast transportation system vulnerabilities and guide investment in resilience-oriented improvements. The research supports KYTC's broader goal of transitioning from reactive disaster response to proactive resilience planning.

ROCKFALL AND ROADSLIDE STUDIES

KYTC is undertaking targeted planning studies to identify and assess the most problematic rockfall and roadslide locations along critical routes in Districts 10 and 12. These studies are designed to strengthen asset management by addressing the rockfall/roadslide hazards that pose significant safety risks, recurring maintenance costs, and potential long-term closures with costly detours, impacts that are often amplified during natural disasters.

The studies compile a comprehensive database of at-risk locations using KYTC's Operations Management System (OMS), input from District and Central Office maintenance staff, and existing Continuous Highway Analysis Framework (CHAF) projects. For each location, proposed improvement strategies include cost estimates and benefit-cost analyses. The outcome is a ranked list of locations based on their critical impact on the transportation network. This process also supports CHAF development and preparation for future funding opportunities, including competitive federal grants.

4.2: PREPARE

KYTC focuses on readiness by developing plans, resources, and training that enable quick, coordinated action when disasters occur. These efforts ensure the agency can maintain essential transportation services, protect public safety, and support recovery across the Commonwealth.

4.2.1: OPERATIONS & MAINTENANCE

KYTC conducts operations and maintenance activities in advance of storms to keep traffic moving and avoid issues. Such activities include:

- Proactively cleaning culverts of debris before a large rain event.
- Prepositioning maintenance vehicles (i.e. snow plows) in advance of storms.

4.2.2: POTENTIAL DETOUR ROUTES

KYTC is conducting a major detour study with the Kentucky State Police to identify potential detour routes around road segments that are likely to be damaged in the future given their proximity to high hazard areas (e.g., near rivers).

4.2.3: COMMUNICATION

Effective communication is a critical component of KYTC's disaster preparedness and response strategy, ensuring that vital information is shared promptly within the agency and with the public. Regarding disaster preparedness, KYTC conducts the following:

- Disseminates information both internally and to the public on disaster preparation and the importance of transportation system resilience.
- Develops disaster aid training courses to educate and train KYTC staff to improve the efficiency and effectiveness of disaster response.

Source: KYTC

4.3: RESPOND

KYTC relies on resilient systems and established procedures to deliver a well-coordinated response when disasters occur. These measures help limit impacts, protect critical infrastructure, and ensure continuity of essential transportation services across the Commonwealth.

4.3.1: EMERGENCY RESPONSE

KYTC works closely with KYEM to respond to disasters, tailoring its actions to the specific impacts of each event. For example, KYTC's primary focus during tornado events is clearing debris from roads to restore access. The agency also repairs damaged traffic signals, panel signs, mast arms, and lighting infrastructure. However, recent flooding events in Eastern Kentucky have led to significant bridge losses and roadway erosion, especially on county roads (state-maintained bridges generally withstand these events better). KYTC also addresses numerous landslides, slips, and rockfalls caused by heavy rainfall and unstable terrain.

- KYTC is introducing a policy making it easier for staff from one district to assist staff in other impacted districts after a disaster. Each disaster presents unique challenges for Kentucky's transportation network, requiring KYTC to adapt its response strategies to restore safety and mobility as quickly as possible.
- KYTC also has plans in place to revert to alternative communication systems and non-cellular communications technology (e.g., two-way radios, satellite phones) as a means of communication should the cellular network go down after a disaster.
- KYTC uses Mobile Solution for Assessment and Reporting (MSAR), FHWA's platform for field personnel to submit damage assessments (DDIRs) with data, photos, and geolocation, streamlining federal review and funding.

KYTC LEARNING FROM DISASTERS:
IMPROVING FUTURE KYTC DISASTER RESPONSE

Led by KYEM, Commonwealth agencies along with county/local governments meet after major disasters to debrief on what worked in responding to the conditions created by the disaster and what corrective actions are necessary to improve responses in the future. KYTC is a major participant in such meetings. For example, after the 2021 tornado outbreak in western Kentucky and the major floods in eastern Kentucky in 2022, KYEM held meetings with several groups that had participated in disaster response to identify corrective actions. Besides Kentucky EM and KYTC, these meetings included representatives stationed at the State Emergency Operations Center (EOC), county emergency managers, and representatives from Incident Management Teams (IMTs) deployed to the scenes of both disasters. Part of this post-disaster attention focused on transportation-related issues. For example, it was noted that KYTC, the Kentucky National Guard (KYNG), and the Kentucky Division of Forestry (KDOF) worked well together in coordinating debris removal after the 2022 flooding. KYTC dispatched 200 trucks to facilitate debris management and performed over 1,000 bridge inspections during the response.

- The discussions also identified areas of concern. For example, IMT members focused on concerns relating to debris removal, including:
- Fallen power lines delayed road clearance due to a power company's hesitation to remove another utility company's lines.
- Each IMT should include debris management expertise.
- Routes to vital facilities should be given priority for debris clearance.
- The Emergency Resource Inventory List is not maintained by all counties thereby limiting the visibility of sharable resources.
- County personnel need training on debris management regarding pickup, segregation, and monitoring.

At the agency level, improved coordination between KYTC and county highway departments was recommended (for example, having KYTC representatives present in county EOCs), as was making different agency asset inventory databases more compatible, and pre-designating debris sites prior to their need. Steps have been taken to implement the recommendations from the after-incident debriefings.

Source: KYTC

4.4: RECOVER

KYTC focuses on restoring transportation systems quickly while improving them to better withstand future events. Recovery efforts aim not just to repair damage but to strengthen infrastructure and enhance long-term resilience across the Commonwealth.

4.4.1: HISTORIC AND REPEATED DAMAGES

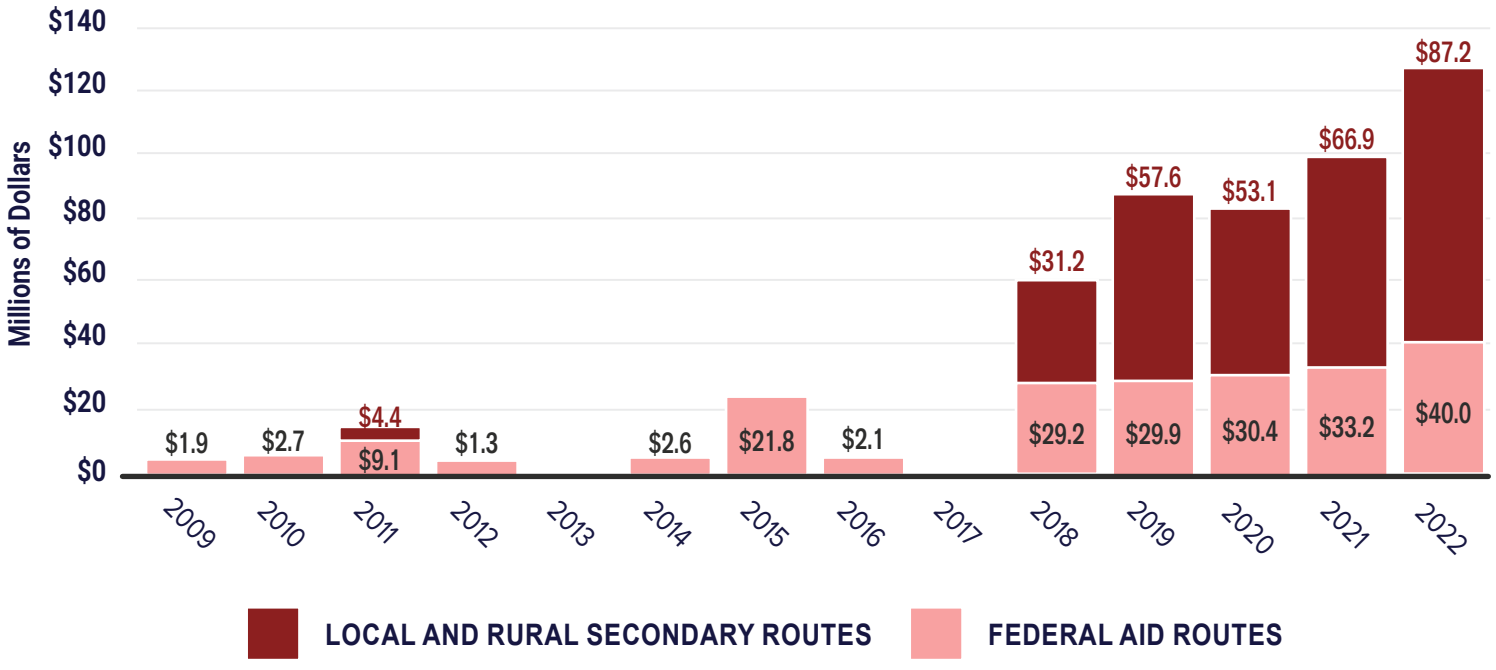
KYTC maintains a database for monitoring and tracking data pertaining to damage and emergency repairs resulting from natural hazards. The database, which goes back to 2009 and is current through 2021, includes over 2,500 records of highway damage and repairs **(Figure 10)**. This includes records on both federal-aid routes eligible for reimbursement through the FHWA Emergency Repair (ER) program as well as those on local and rural secondary roads eligible for reimbursement through FEMA. KYTC updates the database following each new emergency event.

Where available, KYTC also includes in the database estimated costs for highway repairs. Estimated costs for repairs in the database total nearly $530 million. Of this total, $204 million was for damages to federal-aid routes and $301 million was for local and rural secondary routes. The database also demonstrates how repair costs have increased over time, as 90% of the total repair costs were incurred after 2018.

For FHWA ER sites, federal regulation 23 CFR 667 requires each state to periodically conduct a statewide evaluation to determine if there are reasonable alternatives to repairing or reconstructing roads, highways, and bridges with two or more emergency events. Using the ER database, KYTC has identified 211 locations where emergency repairs have been necessary on more than one occasion across multiple years. KYTC uses the information contained in the database to perform the necessary site evaluations to identify alternatives for mitigating the root cause of the recurring damage, estimating the repair costs, and determining the estimated life of the solution.

Though Kentucky's damage and repair sites are spread throughout the state, they are concentrated most heavily in the eastern, mountainous areas. This area is particularly vulnerable to storm-related damage due to the rugged topography, which, during a heavy rain event, funnels the water down slopes and into stream channels in the valleys. This results in a rapid rise of water levels and swift currents. Due to the topography, highways are commonly built alongside these streams in the valleys. As a result, flash flooding in such areas is particularly destructive and can lead to roadway flooding, embankment failures, slips, slides, and washouts.

FIGURE 10: KYTC ESTIMATED REPAIR COSTS BY YEAR FOR DECLARED DISASTERS BETWEEN 2009 - 2022



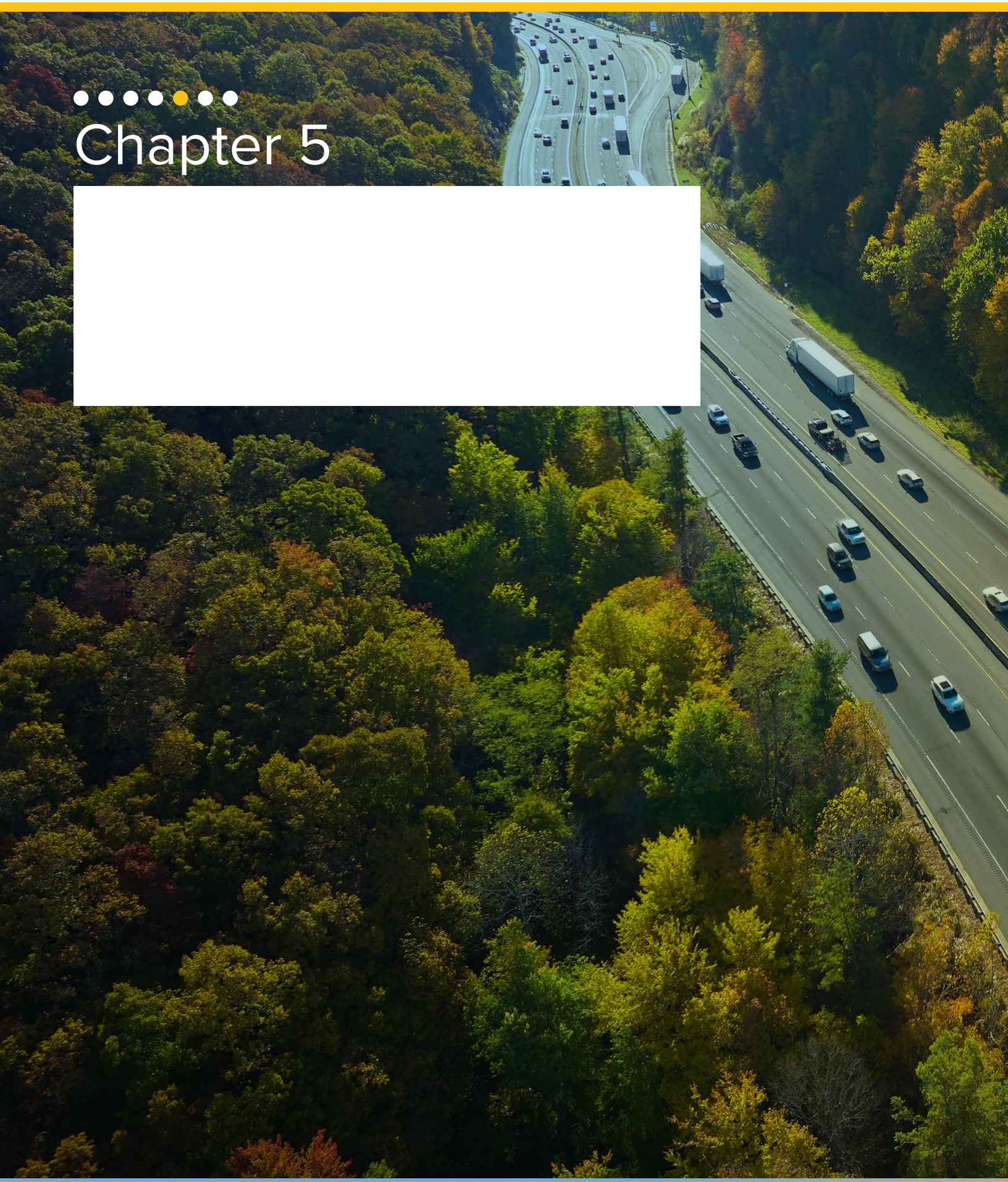
Source: KYTC Dashboard

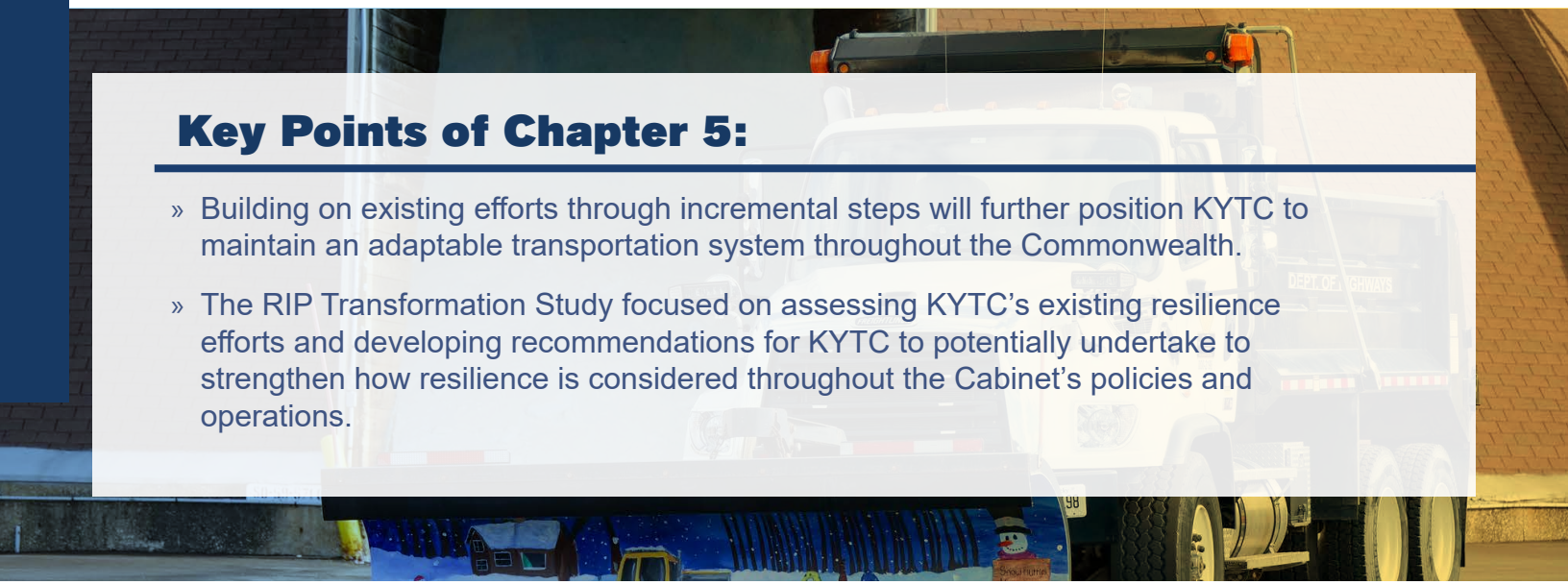
KYTC RECOVERY EFFORTS AFTER THE MAY 2025 LONDON–SOMERSET TORNADO

Following the May 16, 2025 EF-4 tornado that devastated London and Somerset, KYTC mobilized crews to clear downed trees, reopen blocked corridors, and assess widespread roadway and embankment damage caused by the violent long-track storm. The tornado carved a destructive path across Pulaski and Laurel counties, producing catastrophic structural failures and massive debris fields that impeded transportation access, prompting rapid state-led recovery operations to restore mobility.

Source: KYTC

Chapter 5





Key Points of Chapter 5:

- Building on existing efforts through incremental steps will further position KYTC to maintain an adaptable transportation system throughout the Commonwealth.
- The RIP Transformation Study focused on assessing KYTC's existing resilience efforts and developing recommendations for KYTC to potentially undertake to strengthen how resilience is considered throughout the Cabinet's policies and operations.

The RIP Transformation Study has offered recommendations for integrating resilience into KYTC's planning, programming, project design, and operations and maintenance activities. KYTC may consider adopting those recommendations that offer the most cost-effective improvements to its operational practices and program development efforts.

5.1: AGENCY POLICY & GUIDANCE

A comprehensive resiliency framework is needed to guide all stages of a project—from initial planning through implementation and ongoing maintenance. Resilience should not be limited to planning, design, or emergency management; it must be a principle that spans all functional areas within the agency and is integrated throughout the process.

RECOMMENDATIONS INCLUDE:

- KYTC could develop and adopt a policy statement that emphasizes the importance of resilience to both KYTC and the Commonwealth. This statement would define the role resilience plays in decision-making and in shaping project designs. Additionally, KYTC's current resilience goal can be refined, if necessary, and better aligned with other agency goals. These integrated goals would help inform transportation plans, internal guidance, and materials intended for external stakeholders. See Task 1.4 Memo in Appendix B for more information.

5.2: STAFF RESOURCES & KNOWLEDGE

Clarifying how resilience is defined—and emphasizing the benefits of investing in resilience actions—would strengthen KYTC's ability to incorporate resilience into both daily operations and long-term planning. Providing this clarity can empower staff to make informed decisions that enhance the agency's capacity to deliver transportation systems that are adaptable, sustainable, and better prepared for future challenges.

RECOMMENDATIONS INCLUDE:

- Examine current training opportunities offered to KYTC staff and consultant partners and identify how resilience concerns could be incorporated. One example is to include information on how resilience can be incorporated into planning and design phases in the PM Bootcamp Xpress.
- Provide opportunities for KYTC staff to receive resilience-specific training related to their role. These opportunities could be through existing external courses or through courses developed by KYTC.

5.3: COMMUNICATION

Consistently communicating KYTC's experience with and its strategy for enhancing transportation system resilience is an important part of a state DOT's resilience strategy. Clear internal communications can bolster participation and buy in from staff. Through external communications focusing on key audiences, KYTC can build a constituency for investing in resilience improvements to the transportation system that will have important benefits to the Commonwealth.

RECOMMENDATIONS INCLUDE:

- Prepare written internal documentation stating KYTC's definition of resilience, resilience goals, and an established means of exchanging information amongst staff and coordinating resilience efforts where necessary.
- Highlight KYTC resilience successes on a range of traditional and social media outlets. Emphasize the benefits of investing in transportation system resilience.
- Periodically assess the successes and failures in resilience communication strategies to identify those that have been effective and those that may need to be adjusted or discarded from use. This will permit the agency to emphasize communication strategies that have proven successful.
- Continue to support a broader resilience communications strategy that includes other agencies to promote consistent messaging on the importance of resilience in the transportation system.
- Update and refine the information disseminated on KYTC's resilience efforts. Updates would best occur on a set schedule and focus on information found on KYTC's website.

5.4: PERFORMANCE MONITORING

Monitoring and assessing the performance of applied resilience strategies and actions is important in evaluating the effectiveness of these approaches.

RECOMMENDATIONS INCLUDE:

- Develop a performance measure framework consisting of both output and outcome measures that can be used in a KYTC "resilience" story. This would include measures that are already part of KYTC's data collection process (e.g., Interstate trip reliability) and relevant metrics from asset management. Examples of potential performance measures are described in the memo, Goals, Objectives, and Performance Measures in Appendix C.

5.5: PROJECT PROGRAMMING

KYTC has an opportunity to embed resilience further into its project programming process. Through the following recommendations, the Cabinet can strengthen the connection between resilience and funding decisions.

RECOMMENDATIONS INCLUDE:

- Adopt a geospatial analysis approach that overlays proposed projects from both its asset management and capital project planning processes. This would allow the agency to assign risk scores to various assets based on their exposure to environmental stressors.
- Current KYTC practice derives vulnerability assessment scores from a subjective rating system that assigns points to different asset condition factors—providing a general indication of each asset's vulnerability. Currently, KTC is developing a risk monetization tool that assigns dollar values to the risks associated with system disruptions. These values reflect potential impacts not only on KYTC but also on transportation system users and surrounding communities. By quantifying risk in monetary terms, KYTC will be better equipped to evaluate proposed projects in the context of their ability to reduce risk—essentially, their resilience benefits. Whether using the existing vulnerability scores or the forthcoming monetized risk model, overlaying project locations with vulnerability data will help KYTC identify which projects offer the greatest resilience value to the Commonwealth.

5.6: IMPLEMENTATION OF FUTURE ADAPTATION NEEDS

Much of KYTC's future climate risk adaptation work (as opposed to general resilience work) to date has been research-based. The primary focus has been to identify the types and potential impacts of the natural hazards KYTC is facing today and will likely face in the future. Unlike other aspects of resilience work, there has been less mainstreaming of climate adaptation, including use of future climate projections, into everyday agency activities.

RECOMMENDATIONS INCLUDE:

- KYTC could consider future climate projections in any activities that could be influenced by climate/weather. Examples include:
  - Considering future projections in the design of new projects
  - Dedicating resources to explore adaptation alternatives for assets found to be vulnerable during the systems-level vulnerability assessments (but not otherwise slated for project work in the near-term)
  - Considering how adaptation needs can be incorporated into the project scoring/programming process.

5.7: RISK-BASED DECISION-MAKING

Incorporating risk-based decision-making into KYTC processes presents a valuable opportunity to improve project prioritization and resource allocation. To fully realize this approach, KYTC can enhance data collection and accessibility, adopt advanced analysis tools, and integrate benefit/cost methodologies that support risk-based evaluations. Developing these tools and processes, along with providing staff training on data collection and tool usage, will enable KYTC to make more informed, resilient, and cost-effective decisions.

RECOMMENDATIONS INCLUDE:

- Developing a clear statement of resilience benefits and how they can be considered in KYTC decision-making (e.g., in justifying betterments in FHWA ER applications, value engineering).
- Developing and adopting risk-based analysis tools and methodologies that can be used to support agency decision-making.
- Developing a strategy for acquiring the data that supports risk-based decision-making.

5.8: FUNDING

Funding is a common constraint and one that is difficult to overcome. The PROTECT program provides some funding that can be allocated to resilience-oriented actions, but the level of funding is very limited and FHWA is reviewing the Fiscal Years 2024-2026 Notice of Funding Opportunity. Several states have adopted a strategy to allocate funds for incremental resilience improvements to projects in the development phase. This approach is comparable to the seismic retrofit initiative implemented by KYTC in western Kentucky.

RECOMMENDATIONS INCLUDE:

- KYTC may consider evaluating how allocating funds for incremental resilience improvements could be implemented in its highway program. Clarify what qualifies for PROTECT funding through guidance and training. Given the potential scale of future needs, KYTC might also explore the development of new financing concepts such as public-private partnerships for resilience investments.

5.9: PROJECT DEVELOPMENT

Integrating resilience into project development offers an opportunity to strengthen transportation systems against future challenges. Expanding the understanding of resilience-oriented design parameters and incorporating them into standard project development practices can help achieve this goal. By updating design processes, such as ensuring that design checklists explicitly include resilience factors, and considering alternative design parameters through established processes like design exceptions, projects can proactively embed resilience as a core element.

5.9.1: APPLYING RESILIENCE STRATEGIES

A key part of KYTC's success in bolstering the transportation system's resilience to extreme weather lies in the implementation of resilience enhancements to projects already in the project pipeline and, as funding permits, the delivery of dedicated resilience projects. Understanding the types of resilience strategies that KYTC may implement in response to various natural hazards provides valuable insights for developing such projects. The memo Potential Resilience Strategies (Appendix D) describes specific strategies for each of the most frequently encountered and impactful hazards to Kentucky.

5.9.2: VALUE ENGINEERING

There has been a challenge in the value engineering process of distinguishing between costs and values (or benefits). It is recommended that KYTC monitor how value engineering treats resilience-oriented projects and recognize that the lowest cost action up-front is not necessarily the most valuable thing to do when considering the asset's full lifecycle costs. This requires recognition that a general challenge with resilience is that its long-term benefits are associated with often higher short-term upfront costs. Thus, it can be difficult to justify and quantify the benefits without using a tool that helps do so. KYTC could institutionalize a framework for quantifying resilience benefits, enabling these insights to inform decision-making across programs and investments—not just in value engineering (see 5.7).

RECOMMENDATIONS INCLUDE:

- Reviewing KYTC project development and design experience with respect to recent disasters and determine if current design criteria are adequate for similar future events where the magnitudes and frequency of occurrence change.
- Assessing KYTC's project development and design guidance to determine how adaptive they are to a range of future hazards.
- Add resilience to the Data Needs Analysis (DNA) form to flag early in the project development process that resilience to natural hazards may need to be considered. This approach will also enable resilience requirements to be incorporated into planning analyses.
- Continue the pilot project that will inventory small drainage assets using a mobile app system to assess condition, needs, and help identify areas of concern and prioritize project selection. This initial pilot focuses on eastern Kentucky where there is a high probability of impact to transportation assets due to a high precipitation event.

5.10: EMERGENCY RESPONSE

Each region of Kentucky has experienced natural disasters, necessitating state-managed responses. KYTC excels in its response efforts. Continuing to enhance preparation strategies and developing a proactive approach prior to events will enable the agency to respond more swiftly and effectively.

RECOMMENDATIONS INCLUDE:

- Examining KYTC's emergency management process and procedures to identify where preparation planning could be enhanced.
- Implementing steps KYTC can take to improve its disaster response efforts outlined in the KYEM after-action reports. For example, ensure issues relating to contracted services in removing debris are addressed (e.g., contractor pre-qualification improvements).

5.10.1: FEEDBACK LOOPS

The KYEM after-action reports are an impressive example of post-disaster feedback loops that provides agency staff with an understanding of what went right, what went wrong, and how can KYTC do better in the future.

RECOMMENDATIONS INCLUDE:

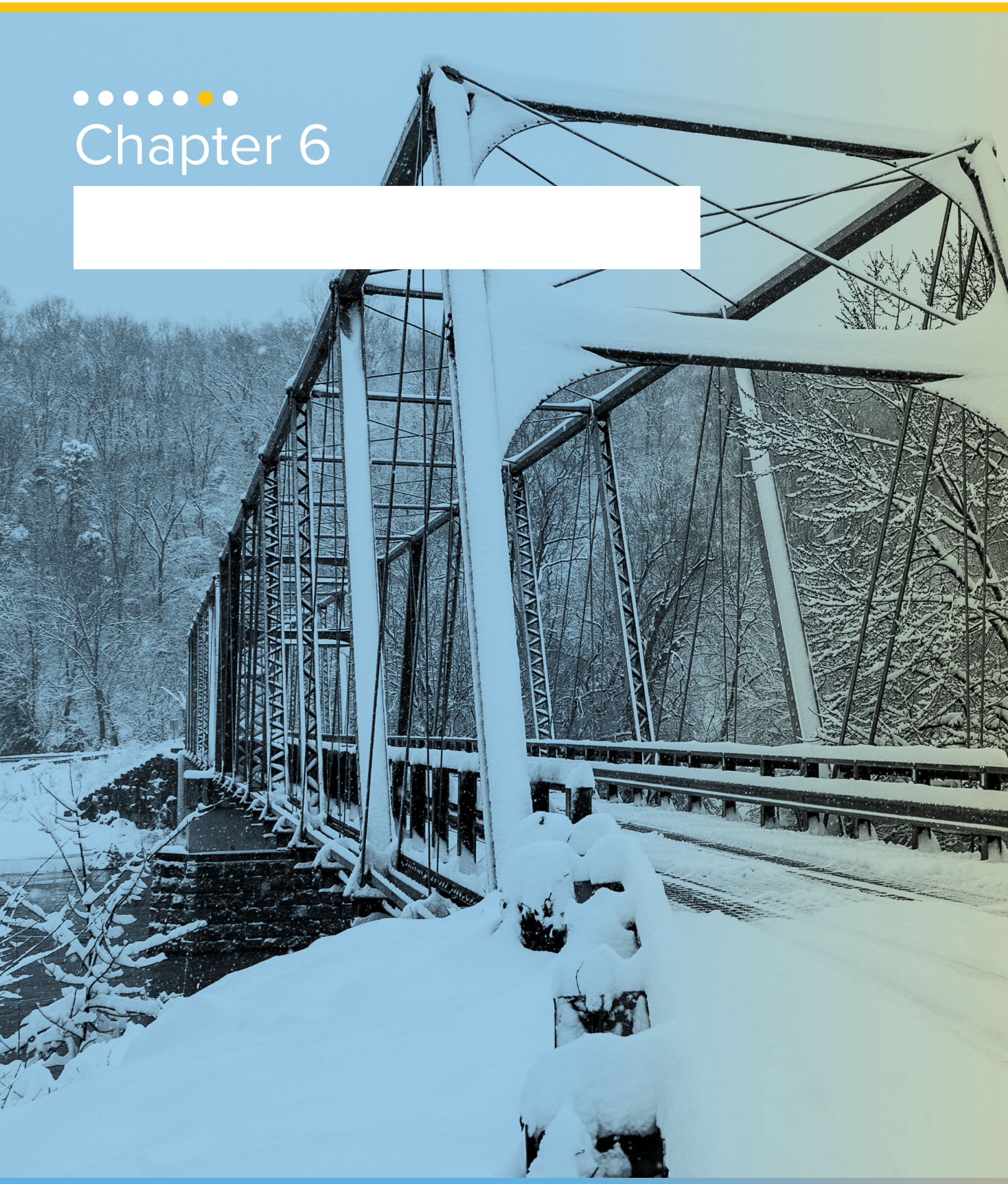
- Establishing a formal feedback mechanism to assess how design parameters are responding to natural disasters as part of a formal diagnosis of why assets failed.
- Conducting research on the failure mechanisms for those assets damaged in recent disasters.

KYTC DEBRIS REMOVAL AFTER THE AUGUST 2022 EASTERN KENTUCKY FLOODING

KYTC led a widespread debris removal within days of the August 2022 Eastern Kentucky floods to clear state rights-of-way across eleven participating counties. By August 11, crews collected a total of 429 truckloads of flood-damaged materials, helping restore safer travel routes and support early recovery efforts.

Source: KYTC

Chapter 6



WEIGHT
LIMIT
15
TONS

CONCLUSION

The Resilience Improvement Plan establishes a proactive framework for safeguarding Kentucky's transportation infrastructure against the impacts of extreme weather and other natural hazards. While it is not possible to eliminate all risks, this plan offers strategies that strengthen system durability, reduce vulnerabilities, and help ensure continuity of transportation access and operations for communities across the state.

The RIP describes how it interacts with other KYTC plans and related research and studies. It also provides a summary of climate and geologic hazards that may impact Kentucky's transportation system, including projections of how these impacts may change in the future. The RIP then describes how KYTC puts resilience into action through mitigation, preparation, response, and recovery. Finally, potential future resilience strategies, derived from the RIP Transformation Project, are described.

The RIP immediately focuses on state owned pavement and bridges to develop methodology due to the relatively robust data set available for historic damage. The critical transportation asset data set will be used to prioritize other modes and systems as the plan is expanded with the help of other government agencies and entities including Metropolitan Planning Organizations and Cities **(Table 4)**. Transit and bicycle/pedestrian facilities will likely be prioritized.

All projects developed by KYTC, including through emergency response and resiliency improvement strategies, follow standard specifications derived from Federal Highway Administration, KYTC design standards, and other applicable regulatory requirements. KYTC ensures adequate contractor oversight to certify all requirements are substantially met. It is important to note that improved resilience through the built environment will partly depend on design standards and specifications. These strategies will be further developed through the ongoing research with KTC.

KYTC is committed to making informed decisions that balance immediate needs with long-term sustainability. This plan represents an ongoing commitment to adapt, innovate, and protect Kentucky's transportation network for future generations.

TABLE 4: POTENTIAL CRITICAL TRANSPORTATION ASSETS TO CONSIDER IN FUTURE RIP UPDATES

Transportation Assets	Summary	GIS
All Roads Measured:	**89,134.2 miles**	Y
Hospitals:	**115 total hospitals** (69 acute license) (28 critical access) (12 psychiatric) (6 rehab)	Y
City Points:	**420 city points**	Y
Dams:	**1,084 dams**	Y
Bridge Locations:	**18,801 bridges** (2,853,604.5 miles)	Y
Airports:	**148 airports** 111 heliports 3 ultralights	Y
FAA Airport Runways:	**59 runways** (162,125,009.9 sq. feet)	Y
Truck Stop Parking:	**36 stops** (1,189 parking spots)	Y
North American Rail Network:	**3,583 miles**	Y
Rail Switchyards:	**80 switchyards** (153,838,148.7 sq. feet)	Y
Amtrak Routes:	**198.1 miles**	Y
Amtrak Stations:	**7 stations**	Y
Commercially Navigable Rivers:	**1,160.1 miles**	Y
All Navigable Waterways:	**2,085.5 miles**	Y
Major Ports:	**7 ports**	Y
All Ports:	**656 ports**	Y
Ferry Routes:	**22,055.9 miles**	Y
Ferry Terminals:	**16 terminals**	Y
Waterway Locks:	**23 locks**	Y
Oil and Gas Wells:	**158,282 wells**	Y
Intermodal Freight Air to Truck:	**12 connections**	Y
Intermodal Freight Rail:	**4 connections**	Y
Transit Agencies:	**4 agencies**	Y
Transit Agencies Routes:	**3,804.3 miles**	Y
Transit Agencies Stops:	**1,675 stops**	Y
Bicycle and Pedestrian Facilities:	**4,785.7 miles**	Y

Appendices

Transportation System Vulnerability and Resilience to Extreme Weather Events and Other Natural Hazards – Final Results of Vulnerability Assessment of National Highway System for All KYTC Districts

Report Number: KTC-18-08/SPR16-524-1F

DOI: https://doi.org/10.13023/KTC.RR.2018.08

The Kentucky Transportation Center is committed to a policy of providing equal opportunities for all persons in recruitment, appointment, promotion, payment, training, and other employment and education practices without regard for economic or social status and will not discriminate on the basis of race, color, ethnic origin, national origin, creed, religion, political belief, sex, sexual orientation, marital status, or age.

Kentucky Transportation Center
College of Engineering, University of Kentucky Lexington, Kentucky

in cooperation with
Kentucky Transportation Cabinet
Commonwealth of Kentucky

© 2018 University of Kentucky, Kentucky Transportation Center
Information may not be used, reproduced, or republished without KTC's written consent.

KENTUCKY Transporation Center

Kentucky Transportation Center • University of Kentucky
176 Raymond Building • Lexington KY 40506 • 859.257.6898 • www.ktc.uky.edu

University of Kentucky

Research Report
KTC-18-08/SPR16-524-1F

Transportation System Vulnerability and Resilience to Extreme Weather Events and Other Natural Hazards — Final Results of Vulnerability Assessment of National Highway System for All KYTC Districts

Benjamin Blandford, Ph.D.
Research Scientist

Scott Schurman
Kentucky Transportation Cabinet

and

Candice Wallace, Ph.D.
Research Scientist

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, Kentucky

In Cooperation With
Kentucky Transportation Cabinet
Commonwealth of Kentucky

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the University of Kentucky, the Kentucky Transportation Center, the Kentucky Transportation Cabinet, the United States Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. The inclusion of manufacturer names or trade names is for identification purposes and should not be considered an endorsement.

May 2018

1. Report No. KTC-18-08/SPR16-524-1F	2. Government Accession No.	3. Recipient's Catalog No
4. Title and Subtitle Transportation System Vulnerability and Resilience to Extreme Weather Events and Other Natural Hazards — Final Results of Vulnerability Assessment of National Highway System for All KYTC Districts		5. Report Date May 2018 6. Performing Organization Code
7. Author(s): Benjamin Blandford, Scott Shurman, Candice Wallace		8. Performing Organization Report No. KTC-18-08/SPR16-524-1F
9. Performing Organization Name and Address Kentucky Transportation Center College of Engineering University of Kentucky Lexington, KY 40506-0281		10. Work Unit No. (TRAIS) 11. Contract or Grant No. SPR 16-524
12. Sponsoring Agency Name and Address Kentucky Transportation Cabinet State Office Building Frankfort, KY 40622		13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes
Prepared in cooperation with the Kentucky Transportation Cabinet

16. Abstract
Recent federal legislation and the Federal Highway Administration (FHWA) have directed state transportation agencies to identify potential vulnerabilities associated with extreme weather events and climate change, develop a risk-based asset management plan, and incorporate findings into transportation planning, design, and maintenance practices. The Kentucky Transportation Center and Kentucky Transportation Cabinet developed and led district-level workshops to elicit local expert knowledge on asset vulnerabilities to natural hazards. Combining the results of these workshops with analysis of available data on assets and hazards, they then performed a natural hazard vulnerability assessment of the state's National Highway System (NHS) for each of Kentucky's 12 districts. The four most critical extreme weather and natural hazards are earthquakes, floods, landslides, and sinkholes. NHS assets such as highway segments, bridges, culverts, and other structures (e.g., overpasses) were assessed for risk to these hazards. Researchers used a modified version of the Federal Highway Administration's Vulnerability Assessment Scoring Tool (VAST). This assessment tool uses an indicator-based approach to assessing vulnerability and promoting resiliency, and results in a vulnerability score for each NHS segment and each hazard type. The output of the assessment process includes a GIS-based data system capable of producing maps that communicate vulnerable locations. Of the 287 NHS segments in Kentucky, 83 were found to have high vulnerability to earthquakes, floods, landslides, or sinkholes.

17. Key Words extreme weather, vulnerability assessment, natural hazard, resilience, flood, earthquake, landslide, sinkhole		18. Distribution Statement Unlimited with approval of the Kentucky Transportation Cabinet	
19. Security Classification (report) Unclassified	20. Security Classification (this page) Unclassified	21. No. of Pages 190	19. Security Classification (report)

Table of Contents

List of Figures iii
List of Tables v
Executive Summary vii
1. Introduction 1
1.1. Overview 1
1.2. Assessment Framework 2
1.3. Historical and Projected Climate in Kentucky 2
1.4. Hazards Considered 2
1.5. KYTC District Workshops 9
1.6. Results 11
1.7. Discussion 19
2. KYTC District 2 20
2.1. District Overview 20
2.2. Hazards 21
2.3. Workshop 28
2.4. Results 34
3. KYTC District 3 36
3.1. District Overview 36
3.2. Hazards 36
3.3. Workshop 42
3.4. Results 48
4. KYTC District 4 49
4.1. District Overview 49
4.2. Hazards 50
4.3. Workshop 56
4.4. Results 59
5. KYTC District 5 61
5.1. District Overview 61
5.2. Hazards 62
5.3. Workshop 68
5.4. Results 72
6. District 6 73
6.1. KYTC District Overview 73
6.2. Hazards 74
6.3. Workshop 80
6.4. Results 86
7. KYTC District 7 87
7.1. District Overview 87
7.2. Hazards 88
7.3. Workshop 94
7.4. Results 100
8. KYTC District 8 101

8.1. District Overview 101
8.2. Hazards 102
8.3. Workshop 108
8.4. Results 113
9. KYTC District 9 114
9.1. District Overview 114
9.2. Hazards 115
9.3. Workshop 121
9.4. Results 126
10. District 10 127
10.1. District Overview 127
10.2. Hazards 128
10.3. Workshop 134
10.4. Results 139
11. KYTC District 11 140
11.1. District Overview 140
11.2. Hazards 141
11.3. Workshop 147
11.4. Results 152
12. KYTC District 12 153
12.1. District Overview 153
12.2. Hazards 154
12.3. Workshop 160
12.4. Results 165
13. References 166
14. Appendices 168
14.1. Appendix 1: VAST Data Inputs 168
14.2. Appendix 2: VAST Results for All NHS Segments 171

List of Figures

Figure 1-1. Mapped VAST results for flood vulnerability of Kentucky's NHS....13
Figure 1-2. Mapped VAST results for earthquake vulnerability of Kentucky's NHS....14
Figure 1-3. Mapped VAST results for landslide vulnerability of Kentucky's NHS....14
Figure 1-4. Mapped VAST results for sinkhole vulnerability of Kentucky's NHS....15
Figure 2-1. KYTC District 2 NHS....20
Figure 2-2.USGS PGA zones in KYTC District 2....23
Figure 2-3. KYTC District 2; location of 100-year floodplain....24
Figure 2-4. KYTC District 2 documented landslides and landslide susceptibility....25
Figure 2-5. Karst potential and sinkholes in KYTC District 2....27
Figure 3-1. KYTC District 3 NHS....36
Figure 3-2. USGS PGA zones in KYTC District 3....38
Figure 3-3. KYTC District 3; location of 100-year floodplain....39
Figure 3-4. KYTC District 3 documented landslides and landslide susceptibility....40
Figure 3-5. Karst potential and sinkholes in KYTC District 3....41
Figure 4-1. KYTC District 4 NHS....49
Figure 4-2. USGS PGA zones in KYTC District 4....52
Figure 4-3. KYTC District 4; location of 100-year floodplain....53
Figure 4-4. KYTC District 4 documented landslides and landslide susceptibility....54
Figure 4-5. Karst potential and sinkholes in KYTC District 4....55
Figure 5-1. KYTC District 5 NHS....61
Figure 5-2. USGS PGA Zones in KYTC District 5....64
Figure 5-3. KYTC District 5; location of 100-year floodplain....65
Figure 5-4. KYTC District 5 documented landslides and landslide susceptibility....66
Figure 5-5. Karst potential and sinkholes in KYTC District 5....67
Figure 6-1. KYTC District 6 NHS....73
Figure 6-2. USGS PGA Zones in KYTC District 6....76
Figure 6-3.KYTC District 6; location of 100-year floodplain....77
Figure 6-4.KYTC District 6 landslide susceptibility and incidences....78
Figure 6-5. Karst potential and sinkholes in KYTC District 6....79
Figure 7-1. KYTC District 7 NHS....87
Figure 7-2.USGS PGA Zones in KYTC District 7....90
Figure 7-3. KYTC District 7; location of 100-year floodplain....91
Figure 7-4.KYTC District 7 landslide susceptibility and incidences....92
Figure 7-5. Karst potential and sinkholes in KYTC District 7....93
KYTC Figure 8-1. KYTC District 8 NHS....101
Figure 8-2. USGS PGA Zones in KYTC District 8....104
Figure 8-3. KYTC District 8; location of 100-year floodplain....105
Figure 8-4. KYTC District 8 landslide incidence and susceptibility....106
Figure 8-5. Karst potential and sinkholes in KYTC District 8....107
Figure 9-1.KYTC District 9 NHS....114
Figure 9-2. PGA Zones in KYTC District 9....117
Figure 9-3. KYTC District 9; location of 100-year floodplain....118

Figure 9-4. Landslide incidence and susceptibility in KYTC District 9 119
Figure 9-5. Karst potential and sinkholes in KYTC District 9 120
Figure 10-1.KYTC District 10 NHS 127
Figure 10-2. USGS PGA Zones in KYTC District 10 130
Figure 10-3. KYTC District 10; location of 100-year floodplain 131
Figure 10-4. Landslide incidence and susceptibility in KYTC District 10. 132
Figure 10-5. Karst potential and sinkholes in KYTC District 10. 133
Figure 11-1. KYTC District 11 NHS. 140
Figure 11-2. USGS PGA Zones in KYTC District 11. 143
Figure 11-3. KYTC District 11; location of 100-year floodplain 144
Figure 11-4. Landslide incidence and susceptibility in KYTC District 11. 145
Figure 11-5. Karst potential and sinkholes in KYTC District 11. 146
Figure 12-1. KYTC District 12 NHS. 153
Figure 12-2. PGA Zones in KYTC District 12 156
Figure 12-3. KYTC District 12 100-year floodplain 157
Figure 12-4. Landslide incidence and susceptibility in KYTC District 12. 158
Figure 12-5. Karst potential and sinkholes in KYTC District 12. 159

List of Tables

Table 1-1. Summary of KYTC statewide NHS assets and natural hazard indicators 4
Table 1-2. Modified Mercalli Intensity Scale / Richter Scale / Peak Ground Acceleration Scale comparisons 6
Table 1-3. Location and date of completion for each of the workshops 10
Table 1-4. All NHS assets in Kentucky with a vulnerability score 3.5 or greater on a scale of 1 to 4 15
Table 2-1. Summary of KYTC District 2 NHS assets and natural hazard indicators 22
Table 2-2. District 2 workshop polling results showing criticality, impacts, and vulnerability 29
Table 2-3. District 2 NHS segments and flood 31
Table 2-4. District 2 NHS assets with vulnerability score 3.5 or greater 35
Table 3-1. Summary of KYTC District 3 NHS assets and natural hazard indicators 37
Table 3-2. District 3 workshop polling results showing criticality, impacts, and vulnerability 43
Table 3-3. District 3 NHS segments and flood 44
Table 3-4. Results of District 3 consensus workshop 46
Table 3-5. District 3 NHS assets with vulnerability score 3.5 or greater 48
Table 4-1. Summary of District 4 NHS assets and natural hazard indicators 51
Table 4-2. District 4 workshop polling results showing criticality, impacts, and vulnerability 57
Table 4-3. District 4 NHS segments and flood 58
Table 4-4. Results of District 4 consensus workshop 59
Table 4-5. District 4 NHS assets with vulnerability score 3.5 or greater 59
Table 5-1. Summary of District 5 NHS assets and natural hazard indicators 63
Table 5-2. KYTC District 5 workshop polling results showing criticality, impacts, and vulnerability 69
Table 5-3. District 5 NHS segments and flood 71
Table 5-4. Results of District 5 consensus workshop 72
Table 5-5. District 5 NHS assets with vulnerability score 3.5 or greater 72
Table 6-1. Summary of District 6 NHS assets and natural hazard indicators 75
Table 6-2. KYTC District 6 workshop polling results showing criticality, impacts, and vulnerability 81
Table 6-3. District 6 NHS segments and flood 83
Table 6-4. Results of District 6 consensus workshop 85
Table 6-5. District 6 NHS assets with vulnerability score 3.5 or greater 86
Table 7-1. Summary of KYTC District 7 NHS assets and natural hazard indicators 89
Table 7-2. District 7 workshop polling results showing criticality, impacts, and vulnerability 95
Table 7-3. District 7 NHS segments and flood 97
Table 7-4. Results of District 7 consensus workshop 99
Table 7-5. District 7 NHS assets with vulnerability score 3.5 or greater 100
Table 8-1. Summary of District 8 NHS assets and natural hazard indicators 103
Table 8-2. District 8 workshop polling results showing criticality, impacts, and vulnerability 109
Table 8-3. KYTC District 8 NHS segments and flood 110
Table 8-4. Results of KYTC District 8 consensus workshop 112
Table 8-5. District 8 NHS assets with vulnerability score 3.5 or greater 113

Table 9-1. Summary of District 9 NHS assets and natural hazard indicators 116
Table 9-2. District 9 workshop polling results showing criticality, impacts, and vulnerability . 122
Table 9-3. District 9 NHS segments and flood 123
Table 9-4. Results of District 9 consensus workshop 125
Table 9-5. District 9 NHS assets with vulnerability score 3.*5 or greater* 126
Table 10-1. Summary of KYTC District 10 NHS assets and natural hazard indicators 129
Table 10-2. District 10 workshop polling results showing criticality, impacts, and vulnerability. 135
Table 10-3. District 10 NHS segments and flood. 136
Table 10-4. Results of District 10 consensus workshop. 138
Table 10-5. District 10 NHS assets with vulnerability score 3.5 or greater 139
Table 11-1. Summary of KYTC District 11 NHS assets and natural hazard indicators. 142
Table 11-2. District 11 workshop polling results showing criticality, impacts, and vulnerability. 148
Table 11-3. District 11 NHS segments and flood. 149
Table 11-4. Results of District 11 consensus workshop. 151
Table 11-5. District 11 NHS assets with vulnerability score 3.5 or greater 152
Table 12-1. Summary of KYTC District 12 NHS assets and natural hazard indicators. 155
Table 12-2. District 12 workshop polling results showing criticality, impacts, and vulnerability. 161
Table 12-3. District 12 NHS segments and flood. 162
Table 12-4. Results of District 12 consensus workshop. 164
Table 12-5. District 12 NHS assets with vulnerability score 3.5 or greater 165

Executive Summary

The Kentucky Transportation Center and Kentucky Transportation Cabinet completed a natural hazard vulnerability assessment of the state's National Highway System (NHS). The assessment was designed as a hybrid process that 1) gathered and analyzed existing and available quantitative data on natural hazards, including meteorological hazards and geological hazards; 2) executed a series of workshops at KYTC districts throughout the state; and 3) incorporated all data into a single vulnerability assessment.

The assessment centered on four extreme weather and natural hazards: earthquake, flood, landslide, and sinkhole. Workshops were held at each of the 12 KYTC districts to elicit local expert knowledge on transportation system vulnerabilities. The workshops involved several facilitated exercises, including map-based discussions and keypad exercises to identify vulnerabilities along highway segments. Data from the mapping and keypad exercises were gathered in a Geographic Information System (GIS) and combined with the other hazard data to identify vulnerabilities for each highway segment.

To combine all data into a comprehensive vulnerability assessment, the team used a modified version of the Federal Highway Administration's Vulnerability Assessment Scoring Tool (VAST). This assessment tool provides an indicator-based approach to assessing vulnerability and promoting resiliency. For this evaluation, the NHS was divided into 287 segments. Each segment was scored against 22 data layers related to risk exposure, asset sensitivity, and system adaptive capacity. The VAST analysis results in an overall vulnerability score for each NHS segment to each hazard type, with a higher score indicating higher vulnerability. Of the 287 NHS segments, 83 were found to have high vulnerability to either earthquake, flood, landslide, or sinkhole. Of these 83 segments, 13 had high vulnerability to two hazard types, and one other segment had high vulnerability to three hazard types. In terms of hazard types, 4 were vulnerable to earthquake, 27 were vulnerable to flood, 45 were vulnerable to landslide, and 22 were vulnerable to sinkhole.

1. Introduction

1.1.Overview

This report is the second and final in a series examining the vulnerability of Kentucky's National Highway System (NHS) assets to extreme weather events and other natural hazards. The first assessment report, *Transportation System Vulnerability and Resilience to Extreme Weather and Other Natural Hazards: Report for Pilot Project – KYTC District 1, KTC_16-20/SPR16-524-1F*, can be accessed at http://www.ktc.uky.edu/projects/transportation-system-vulnerability-and-resilience-to-extreme-weather-events-and-other-natural-hazards/.

KTC's research objective is to assist the Kentucky Transportation Cabinet (KYTC) in its efforts to identify assets that are at greatest risk from the effects of natural hazards. Once high risk assets have been identified, mitigation strategies can then be developed to help offset the effects of natural hazard vulnerabilities and to improve the resiliency of the overall NHS transportation infrastructure across Kentucky. Recent federal legislation calls for state transportation agencies to develop a risk-based asset management plan for NHS assets that considers natural hazards. Similarly, the Federal Highway Administration (FHWA) calls for state transportation agencies to identify potential vulnerabilities associated with extreme weather events and climate change, and to incorporate these findings into transportation planning, design, and maintenance practices.[1]

This report presents the findings from workshops conducted at KYTC Districts 2-12. The District 1 assessment is included in the initial report. This assessment process solicits participation from KYTC Divisions in order to:

a) Develop a method for assessing vulnerability of identified assets to extreme weather events and geological hazards;
b) Perform a vulnerability assessment of KYTC's assets that are at risk to extreme weather events;
c) Identify the assets that are at greatest risk to extreme weather and other natural events; and
d) Incorporate the findings and results formulated from the vulnerability assessment into the Cabinet's ongoing decision-making for planning, design, operations and maintenance processes.

The output of the assessment process includes a GIS-based data system compatible with existing Cabinet systems. The extent of the assessment is the NHS as defined by the *Moving Ahead for Progress in the 21st Century Act* (MAP-21). The project results are intended to feed directly into the Cabinet's efforts to develop a risk based asset management plan, as required by MAP-21 and by provisions in the *Fixing America's Surface Transportation Act* (FAST Act).[2] The results also enhance the Cabinet's efforts to address the FHWA directive on transportation system preparedness and resilience to climate change and extreme weather events.

[1] FHWA, "Transportation System Resilience Preparedness and Resilience to Climate Change and Extreme Weather Events."
[2] FHWA, Transportation Asset Management Plans.

1.2.Assessment Framework

FHWA guidance documentation, as well as insights from the other state DOT vulnerability assessments, was used to develop this project design. Ultimately the research team settled on a hybrid approach to conduct the vulnerability assessment. This hybrid approach was divided into three major components: 1) gathering and analysis of available data on assets and hazards, 2) development and implementation of district-level workshops to elicit local expert knowledge on asset vulnerabilities, and 3) incorporating all of the data gathered into a single and ultimate assessment. The results from these efforts were incorporated into a GIS in order to develop a central repository of data, facilitate easy data analysis of hazards and transportation assets, and enable KYTC users to produce maps and geovisualizations to communicate vulnerabilities.

The first phase of this research involved identifying risk associated with extreme weather and other natural hazards. Findings from this phase are covered extensively in the initial project report. The following sections summarize these findings for the most critical extreme weather and natural hazards identified: earthquake, flood, landslide, and sinkhole.

1.3.Historical and Projected Climate in Kentucky

The interim report for this project presented detailed information on historical and future projected climate data for Kentucky.[3] Historical climate data at the county level provided by the Midwest Regional Climate Center demonstrated geographical patterns of extreme precipitation and extreme heat across the state. Western areas of the state have experienced more frequent occurrences of heavy precipitation (greater than 3" in a calendar day) and extreme heat (maximum daily temperature greater than 95 degrees Fahrenheit) than eastern areas.

Future climate projection scenarios for Kentucky were available from the National Climate Development and Advisory Committee.[4] These scenarios project an increase across the state in the annual number of days with a maximum temperature above 95 degrees. Western areas of the state are projected to experience the greatest increase in annual number of days with such extreme heat. The scenarios also project an increase across the state in the annual number of days with extreme precipitation. Central and northern areas of the state are projected to experience the greatest increase in extreme precipitation events.

The historical climate data demonstrate there is significant inter-annual variability in weather, and that is likely to continue going forward. Nonetheless, the climate projections provide a useful tool for understanding the frequency with which weather patterns are likely to occur. For transportation planners, this tool can help formulate informed decisions regarding mitigation efforts to extreme weather events that may become more severe or occur more frequently in the future as a result of climatic changes.

1.4.Hazards Considered

KYTC NHS assets, including highway segments, bridges, culverts, and other structures (overpasses) were assessed for risk against the four major hazards using existing and available

[3] Blandford et al., "Transportation System Vulnerability and Resilience to Extreme Weather Events and Other Natural Hazards."

[4] Kunkel et al., "Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 2. Climate of the Southeast U.S."

data. Table 1-1 summarizes the relationship between these NHS assets statewide and selected hazard indicators.

Table 1-1 Summary of KYTC statewide NHS assets and natural hazard indicators

Asset Type	KYTC Total	PGA* ≥ 60	PGA ≥ 30 and < 60	PGA ≥ 18 and < 30	100-yr Flood Plain	Major Karst Potential	Mod. Karst Potential	High Landslide Potential	Mod. Landslide Potential
Total NHS Road Miles**	6,151	194	425	771	229	1,921	848	1,372	401
Interstate	2,064	31	161	241	49	762	398	290	56
Parkway	1,034	60	61	218	33	209	174	59	77
US Highway	1,932	101	128	295	97	694	136	613	181
KY Routes	1,076	2	76	17	49	227	141	409	86
Local Road	44	0	0	0	0	29	0	0	0
Bridges***	772	51	93	143	431	149	46	231	67
Culverts	292	12	21	21	166	86	40	75	27
Structures	1,409	56	109	178	26	462	188	205	86

* PGA refers to the maximum peak ground acceleration with 2% likelihood of exceedance in 50 years. ** Road miles refers here to centerline miles; for divided highways, centerline miles are doubled. *** Number of bridges and culverts here only include those listed in the National Bridge Inventory database. Bridges, culverts, and pipes shorter than 20 feet are not included.

1.4.1. Seismic

An earthquake refers to "both [the] sudden slip on a fault, and the resulting ground shaking and radiated seismic energy caused by the slip, or by volcanic or magmatic activity, or other sudden stress changes in the earth."[5] Earthquakes are among the most destructive natural forces on Earth. Ground movement caused by an earthquake can damage or destroy buildings, roads, bridges, and other humanly made structures. In certain conditions, earthquakes can trigger other hazards such as landslides and tsunamis.

One way to measure earthquake magnitude is the Richter scale, which measures the amplitude of seismic waves recorded by seismographs. Because the Richter scale is logarithmic, each whole number increase in the scale represents a tenfold increase in amplitude and corresponds to the release of approximately 31 times more energy. As a result, seemingly small differences in earthquake ratings on the Richter scale can entail significant levels of impact.

The Modified Mercalli Scale is also used to measure the effect of an earthquake on the Earth's surface. The scale is based more on observed events than mathematical models, and intensity values are assigned after the fact by evaluating witness statements and structural damage. While there is no direct conversion between the Richter Scale and the Modified Mercalli Scale, the two can be compared in general terms (Table 1-2).

Related to the Richter Scale and the Modified Mercalli Scale is the measure of Peak Ground Acceleration (PGA). PGA is a measure of the Earth's movement at a given location as a result of seismic activity. It accounts for the amount of energy released by an earthquake and how this energy travels through varying types of soil and rock. PGA is particularly useful for implementing engineering design standards for transportation assets and structures.

[5] USGS, "Earthquake Glossary."

Table 1-2. Modified Mercalli Intensity Scale / Richter Scale / Peak Ground Acceleration Scale comparisons[6]

Modified Mercalli Intensity Scale with Corresponding Richter Scale					
Intensity	**Verbal Description**	**Witness Observations**	**Maximum Acceleration (cm/sec^2)**	**Corresponding Richter Scale**	**PGA (%g)**
I	Instrumental	Detectable on seismographs	<1	<3.5	< 0.17
II	Feeble	Felt by some people	<2.5	3.5	.17-1.0
III	Slight	Felt by people resting	<5	4.2	1.0-1.4
IV	Moderate	Felt by people walking	<10	4.5	1.4-3.9
V	Slightly	Sleepers awake; church bells	<25	<4.8	3.9-9.2
VI	Strong	Trees sway; suspended objects swing; objects fall off	<50	5.4	9.2-18
VII	Very Strong	Mild alarm; walls crack; plaster falls	<100	6.1	18-34
VIII	Destructive	Moving cars uncontrollable; masonry fractures; poorly constructed buildings	<250		34-65
IX	Ruinous	Some houses collapse; ground cracks; pipes break open	<500	6.9	65-124
X	Disastrous	Ground cracks profusely; many buildings destroyed; liquefaction and landslides widespread	<750	7.3	> 124
XI	Very Disastrous	Most buildings and bridges collapse; roads, railways, pipes, and cables destroyed; general triggering of other hazards	<980	8.1	
XII	Catastrophic	Total destruction; trees fall; ground rises and falls in waves	>980	>8.1	

1.4.2. Flood

Flooding is one of the most common and widespread natural hazards encountered in Kentucky. It can occur in any season and in any county in the state. Flooding occurs when water overflows onto land that is usually dry. A flood can range from several inches of water spilling onto a roadway, causing minor inconveniences and temporary closures, to several feet of water inundating an area

[6] KYEM, "Commonwealth of Kentucky Enhanced Hazard Mitigation Plan"; Wang, "Ground Motion for the Maximum Credible Earthquake in Kentucky."

— damaging structures and eroding embankments. A flood's severity is influenced by factors such as rainfall intensity and duration, existing ground saturation levels, topography, and land cover. In the U.S., flooding causes on average $5 billion in damages annually.[7]

Kentucky is particularly vulnerable to flooding. There are over 90,000 miles of streams in the state.[8] The two types of flooding that are most common in Kentucky are river floods and flash floods.

- A river flood results from heavy rainfall that persists across a region causing water levels to rise over river banks as the precipitation accumulates in the larger stream channels. River floods can also be caused by rapid snowmelt across a large region. The Ohio River and Mississippi River are especially prone to river flooding due to the large drainage areas that they encompass.
- Flash floods result from excessive rainfall in a short amount of time, causing water levels to rapidly rise and torrents of water to flow through stream channels, urban streets, or mountain valleys. Flash floods can also occur due to dam failure. They are particularly dangerous because of the destructive force of rapidly flowing water and their sudden onset.

The Federal Emergency Management Agency's (FEMA) flood hazard mapping program provides agencies and communities with accurate flood hazard and risk data. Developed as part of this program is the Flood Insurance Rate Map (FIRM) data, including the 100-year digital flood plain mapping.[9] A flood with a 100-year recurrence interval has an approximately 1 percent chance of occurring in a given year. The 100-year floodplain encompasses areas that would be inundated if such a flood were to occur.

1.4.3. Landslide

A landslide is defined as "the movement of a mass of rock, debris, or earth down a slope".[10] Landslide types can be divided into five categories to describe this movement:[11]

- Slides — refers to "mass movements where there is a distinct zone of weakness that separates the slide material from more stable underlying material"
- Falls — refers to abrupt movements of material such as rocks or boulders that have become detached from steep slopes, and movement occurs by free-falling, bouncing, and rolling
- Topples — similar to a fall, however, the movement is characterized by forward rotation of material about some pivotal point
- Flows — includes debris flow, debris avalanche, earthflow, mudflow, and creep
- Lateral spreads — generally occur on gentle slopes or flat terrain. These movements are caused by liquefaction, whereby overly-saturated and loose soil is transformed from a solid to a liquid state

[7] The National Severe Storms Laboratory, "Floods."
[8] KGS, "Water Fact Sheet."
[9] FEMA, "FEMA Flood Map Service Center."
[10] Cruden, "A Simple Definition of a Landslide."
[11] USGS, "Landslide Types and Processes."

Landslides occur throughout the U.S. Because gravity is the fundamental force involved, landslides most frequently occur on steep slopes, such as along mountain ranges. Other contributing factors can include:[12]

- Erosion by water, such as from rivers, glaciers, or ocean waves, which results in the formation of steep slopes
- Soil saturation from heavy rains or snowmelt
- Seismic activity
- Volcanic eruptions
- Human activity, such as mining, vegetation removal, placement of man-made structures, or excess weight from the stockpiling of material on a slope

In Kentucky, landslides are most common in the mountains and plateaus of eastern Kentucky, the Outer Bluegrass, the Knobs region, and the Ohio River Valley.[13]

1.4.4. Karst

Karst topography is "terrain with distinctive hydrology and landforms that arise from a combination of high rock solubility and well developed secondary (fracture) porosity".[14] Sinkholes, caves, sinking streams, and springs are commonly found in karst landscapes. Two types of sinkholes occur commonly in Kentucky — subsidence and cover collapse. Subsidence sinkholes develop gradually as surface water dissolves cavities in the bedrock, causing the ground to move gradually downward. Cover collapse sinkholes result from ground-level materials suddenly collapsing into an underground cavity or cave that has been formed by groundwater dissolving the bedrock.

In Kentucky, karst landscapes occur where limestone or dolostone bedrock lies near the Earth's surface. Weathering of this porous rock from Kentucky's humid climate results in voids in the landscape and can result in sinkholes. In the state, karst potential is highest in the Inner Bluegrass Region, the Western Pennyroyal region, and the Eastern Pennyroyal region. Kentucky is fifth in the nation in terms of impact from sinkholes.[15] Estimates indicate that 55 percent of the land in the state has the potential for karst development. Additionally, 38 percent of the state has enough karst development to be recognized topographically, and 25 percent has well-developed karst features.[16] Sinkholes and karst formation can greatly impact highway infrastructure. Sinkhole formation can lead to the collapse of roadway surfaces, ditch lines, and bridge foundations, necessitating costly repairs.[17] Karst-related flooding can cause temporary road closures, roadway damage, or problems with drainage and rainwater runoff.

1.4.5. Other Hazards

Aside from these four major hazards, Kentucky experiences a variety of other natural and meteorological hazards. For each KYTC district assessment, a quick snapshot is provided on the

[12] USGS.
[13] KGS, "Landslide Hazards in Kentucky."
[14] Ford and Williams, *Karst Hydrogeology and Geomorphology*.
[15] KYEM, "Commonwealth of Kentucky Enhanced Hazard Mitigation Plan."
[16] Currens, "Kentucky Is Karst Country! What You Should Know about Sinkholes and Springs."
[17] Moore and Beck, "Karst Terrane and Transportation Issues."

historical and geographic significance of each of these hazards for the NHS assets in the respective district:

- Snow/Ice
- Freeze/thaw
- Extreme heat
- Drought/wildfire
- Tornado

Impacts from these hazards are generally less severe in terms of damage to the transportation system, though disruptions can be significant. More information on the impacts of these hazards and the data used to assess the hazards' impacts can be found in the first report.

1.5. KYTC District Workshops

For the second phase of this project, KYTC personnel and KTC researchers developed a workshop-based methodology to elicit local expert knowledge from transportation personnel on highway system vulnerabilities. KYTC district workshops were completed for each of the 12 districts. Each workshop consisted of twelve to twenty KYTC personnel representing the transportation areas of maintenance, planning, design, and environmental analysis. KYTC personnel were identified and invited by KYTC leadership to the workshops based on their knowledge, experience, and expertise of their respective district transportation systems. At the workshops, data was collected from participants through a series of facilitated exercises, including: 1) qualitative mapping exercises, and 2) quantitative keypad exercises.

Table 1-3 shows the locations and dates of completion for each of the twelve workshops.

Table 1-3. Location and date of completion for each of the workshops

District	City	Date
1	Paducah	4/21/2016
2	Madisonville	8/25/2016
3	Bowling Green	9/21/2016
4	Elizabethtown	10/4/2016
5	Louisville	10/23/2017
6	Covington	1/18/2017
7	Lexington	3/2/2017
8	Somerset	3/28/2017
9	Flemingsburg	6/7/2017
10	Jackson	10/18/2017
11	Manchester	6/8/2017
12	Pikeville	8/7/2017

1.5.1. Mapping Exercises

The first component of the workshops involved facilitated mapping exercises during which KYTC district personnel identified, provided details on, and discussed with workshop participants highway locations that have flooded, experienced landslide activity (slips, slides, rock falls), or been impacted by sinkholes or karst-related flooding. This local knowledge yielded insights on which areas not located in the 100-year floodplain are vulnerable to flooding due to poor drainage, blocked drains, sinkholes, land use changes, or stream channel maintenance problems, among others. Local personnel also indicated the frequency of such hazards (e.g., "This road floods every time we experience a heavy rainfall"), the duration of the events, and the severity of impacts to the transportation system. Following the mapping exercises, the groups identified and discussed what they believed the worst case scenario could plausibly be for the district's transportation system. This discussion required personnel to consider a number of factors affecting vulnerability, including the importance of the asset, its replacement cost, network redundancy, likelihood of hazard occurring, and severity and extent of potential impacts.

1.5.2. Polling Results

The second component of the workshops involved keypad exercises during which workshop participants rated each NHS highway segment for both their criticality to the overall system and the potential impact of hazard events. The NHS was divided into 287 segments for evaluation. Segmentation of the NHS incorporated several factors, including route number, county, length, functional class, and annual average daily traffic (AADT). The majority of NHS segments were defined as a particular route in a county (e.g., US 60 in Ballard County). In a few cases, multiple routes were combined to form a single NHS segment (e.g., multiple one-block road segments in downtown Louisville). In a few other instances, a particular route in a county was divided into more than one segment (e.g., I-64 in Jefferson County). The average length in centerline miles of the NHS segments statewide is 11.5 miles, with the longest NHS segment being US 119 in Harlan County (39.1 miles), and the shortest NHS segment being CR 1659 in Floyd County (0.2 miles).
Workshop participants were provided with keypads and asked to evaluate each of the NHS segments for criticality and potential impacts from extreme weather and natural hazards. The scales used to define criticality and potential impacts are described below.

Criticality scale

- 1-3: Non-NHS; Low AADT; Alternate routes available
- 4-6: Some NHS; Low to medium AADT; Alternative for other state routes
- 7-9: Interstate; Lifelines; Some NHS; Sole access; No alternate routes

Impacts scale

- 1-3: Results in little or negligible impact to asset. Asset would be available with full use within 10 days and immediate limited use would still available.
- 4-6: Results in minor damage and/or disruption to asset. Asset would be available with either full or limited use within 60 days.
- 7-9: Results in total loss or ruin of asset. Asset may be available for limited use after at least 60 days and would require major repair or rebuild over an extended period of time.

Keypad rankings were conducted in real time. Participants were encouraged to discuss the highway segments as the exercise proceeded through the highway segments, and they were able to view the results immediately. If the rankings varied significantly across the group, a discussion followed to explore why diverging opinions existed, and if necessary, another ranking was conducted to reflect the conversations. Data from the mapping exercises and keypad ranking exercises were gathered and digitized in a GIS.

1.5.3. Consensus Workshop

After completing the first two district workshops, it became apparent from the workshop discussions that natural hazard vulnerabilities are sometimes exacerbated by other issues. Some of these issues were internal to KYTC, such as inadequate funding, not enough staff, or internal policies restricting the ability of maintenance personnel to effectively perform their tasks. Other issues were external to KYTC, such as land use changes that alter rainwater runoff and the extent of the floodplain, waterway channels that are inadequately maintained by land owners, and the need to acquire permitting from other agencies in certain situations. To explore these issues further, participants in workshops for Districts 3 through 12 engaged in a consensus workshop where the following question was posed "What are the Greatest Challenges to Conducting Maintenance in Your District?" Participants were asked to individually brainstorm, discuss their brainstorm ideas with a partner, and share their ideas with the entire group. Results from these consensus workshops are included in the assessment results for each district in the following chapters.

1.6.Results

The third phase of the project incorporated all of the data gathered into a single comprehensive assessment. In order to incorporate all the varying data types, FHWA's Vulnerability Assessment Scoring Tool (VAST) was used to refine the results. This allowed the project team to combine quantitative data gathered from available sources with data generated in the workshops.

1.6.1. VAST

FHWA has supported state DOTs, MPOs, and regional planning organizations in their efforts to better understand transportation system vulnerability and improve resiliency. As part of this effort, FHWA has made available VAST to help transportation organizations implement an indicator-

based assessment of transportation assets.[18] VAST is a Microsoft Excel-based tool for organizing multiple and varying indicator-based types of natural hazard data and their relation to asset vulnerabilities. VAST provides users with a high-level understanding of asset vulnerability, and VAST results enable users to prioritize assets and improve system resiliency.

Data inputs for VAST are organized into three types:

1) Exposure – potential exposure of transportation assets to climate stressors and other hazards. Exposure data may include average number of extreme heat days or extreme precipitation events.
2) Sensitivity – how sensitive the transportation asset is to the particular climate stressors and other hazards. Sensitivity data may include characteristics of the asset or historical occurrences.
3) Adaptive Capacity – how resilient the system is to disruption and/or damage. Adaptive Capacity data may include indicators of asset criticality, such as average annual daily traffic (AADT), functional class, asset replacement value, or detour route viability.

Data are furthermore organized according to what class of asset and what type of hazard are being assessed. VAST is set up to allow users to assess multiple transportation asset classes, including: highways, bridges, railways, ports and waterways, airports, and pipelines. In terms of hazards, VAST is set up to incorporate hazard data on temperature, flooding, sea level rise, storm surge, wind, drought, dust storms, wildfires, winter storms, freeze/thaw cycles, and permafrost thaw. Users are also able to input a new type of asset class or hazard if desired.

For each indicator, transportation assets receive a score from one to four. For exposure and sensitivity indicators, a low score means less exposure or sensitivity while a high score means more exposure or sensitivity. For adaptive capacity indicators, a low score indicates better adaptive capacity while a high score indicates less adaptive capacity. Within each indicator category, individual datasets can be weighted. For example, if one adaptive capacity indicator is believed to be more meaningful than the others, it can be assigned a higher percentage of the adaptive capacity indicator score. Additionally, each indicator type – exposure, sensitivity, and adaptive capacity – is assigned an overall contribution to the final vulnerability score as a percentage. The default setting for each is set at 33% and can be adjusted by the user. The output from VAST is a score from one to four indicating vulnerability of each transportation asset to each hazard type, where a higher score indicates higher vulnerability.

1.6.2. VAST Data Inputs

VAST was used for this project to incorporate multiple and varying datasets pertaining to natural hazard risk and asset criticality. In all, 22 indicator datasets were included for the hazards of earthquake, flooding, landslide, and sinkholes and their relation to Kentucky's NHS. NHS assets were defined as the same highway segments used in the district workshop keypad exercises. Data were obtained from a variety of sources, including existing and available meteorological and geological data, data processed by the project team using GIS, and data produced through the KYTC district workshops. Each of these datasets was classified into categories of Exposure Data, Sensitivity Data, or Adaptive Capacity data. The default setting of 33% weight for each indicator

[18] FHWA, "Vulnerability Assessment Scoring Tool (VAST)."

category was applied. Appendix 1 includes descriptions, thresholds, and data sources for each of the 22 indicators.

1.6.3. VAST Results

Of the 287 NHS segments, 83 were found to have high vulnerability to either earthquake, flood, landslide, or sinkhole. Of these 83 segments, 13 had high vulnerability to two hazard types, and one other segment had high vulnerability to three hazard types. In terms of hazard types, 4 were vulnerable to earthquake, 27 were vulnerable to flood, 45 were vulnerable to landslide, and 22 were vulnerable to sinkhole. Figures 1-1 through 1-4 map the VAST results of NHS vulnerability to each of these four hazards.

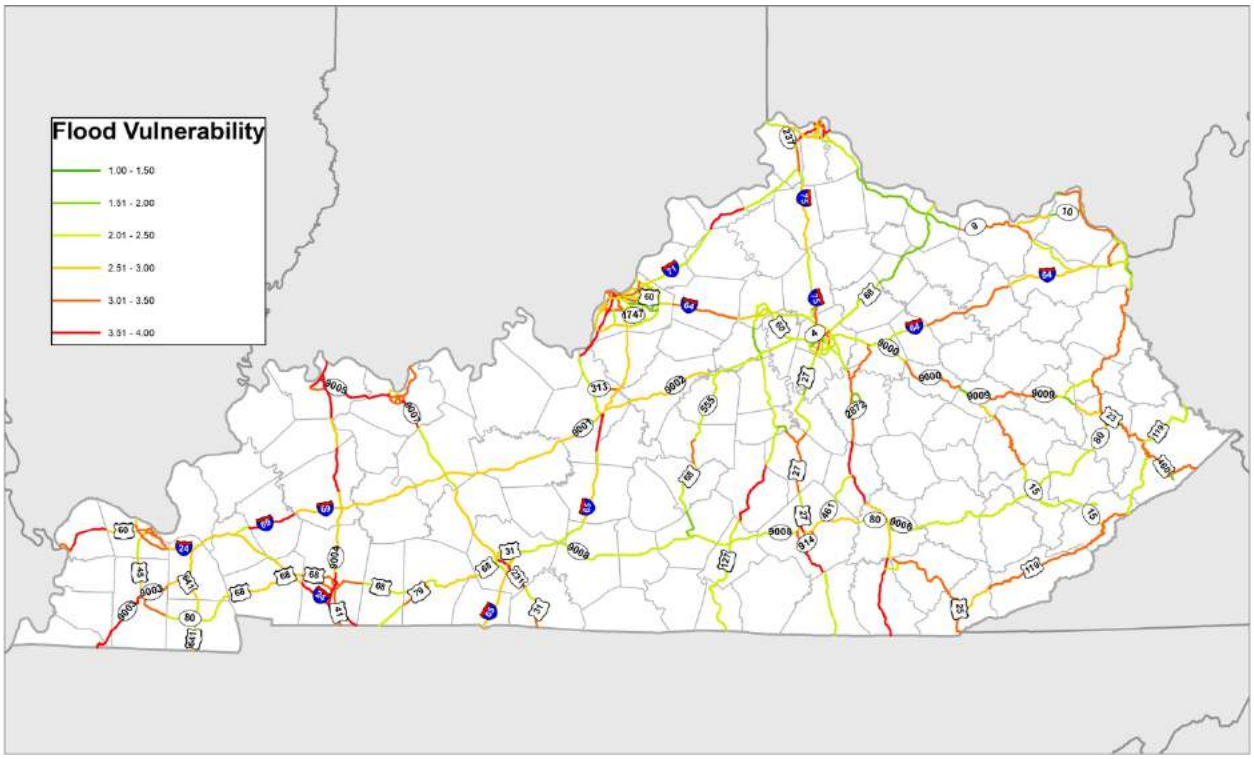


Figure 1-1. Mapped VAST results for flood vulnerability of Kentucky's NHS

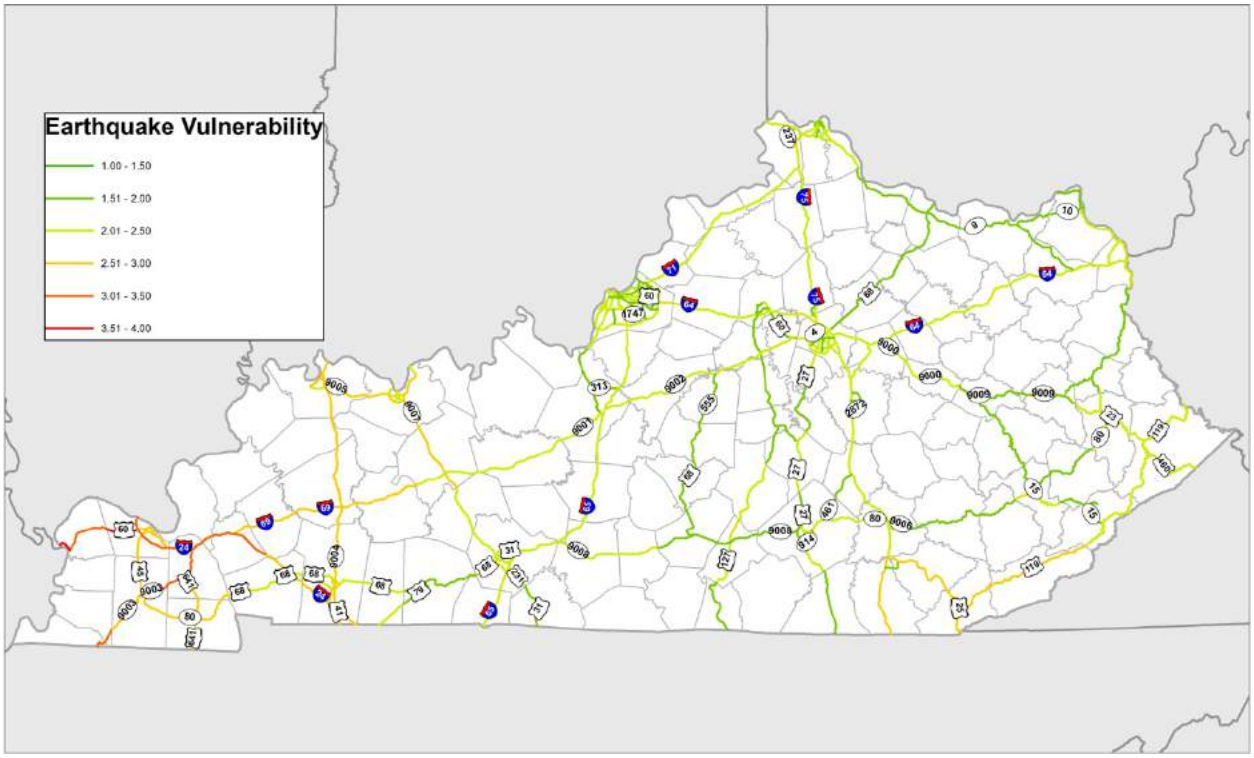


Figure 1-2. Mapped VAST results for earthquake vulnerability of Kentucky's NHS

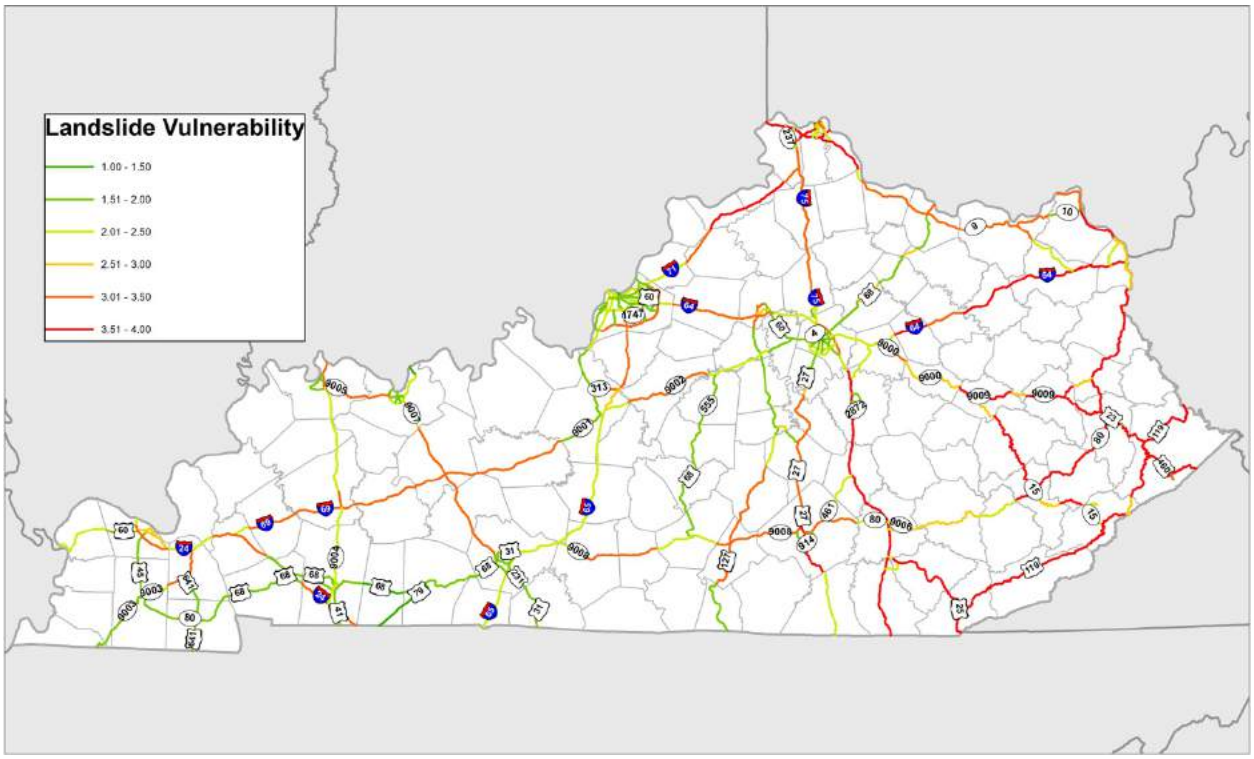


Figure 1-3. Mapped VAST results for landslide vulnerability of Kentucky's NHS

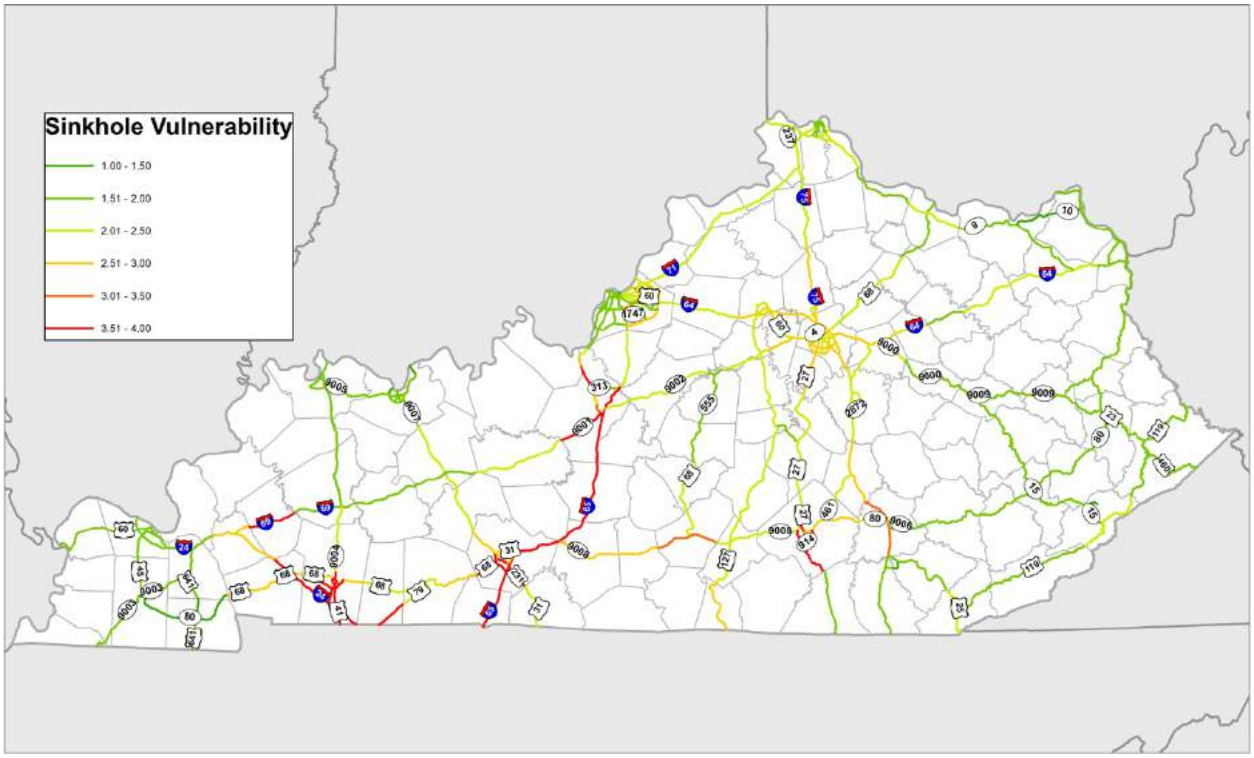


Figure 1-4. Mapped VAST results for sinkhole vulnerability of Kentucky's NHS

Table 1-5 shows the NHS assets with the highest vulnerability to each of the four hazard types (a score of 3.5 or greater). In a few cases, NHS assets are included more than once if they have an elevated vulnerability score to more than one hazard type. A full listing of all NHS assets and vulnerability scores is provided in Appendix 2.

Table 1-4. All NHS assets in Kentucky with a vulnerability score 3.5 or greater: scale of 1 to 4

District	County	Route	Vulnerability Score	Hazard
1	Ballard	US 51	**3.83**	Earthquake
1	Ballard	US 60	**3.54**	Flood
1	Ballard	US 60	**3.50**	Earthquake
1	McCracken	US 60	**3.67**	Earthquake
1	McCracken	I-24	**3.50**	Earthquake
1	Fulton/Hickman	JC 9003	**3.54**	Flood
1	Graves	JC 9003	**3.54**	Flood
1	Trigg	I-24	**3.92**	Sinkhole
2	Caldwell	I-69	**3.62**	Flood
2	Christian	EB 9004	**3.62**	Flood
2	Christian	I-24	**3.54**	Flood
2	Daviess	AU 9005	**3.71**	Flood
2	Daviess	WN 9007	**3.63**	Flood
2	Henderson	AU 9005	**3.54**	Flood

District	County	Route	Vulnerability Score	Hazard
2	Henderson	I-69	**3.54**	Flood
2	Henderson	US 41	**3.87**	Flood
2	Henderson	US 41A	**3.54**	Flood
2	Hopkins	I-69	**3.71**	Flood
2	Caldwell	I-69	**3.72**	Sinkhole
2	Christian	EB 9004	**3.92**	Sinkhole
2	Christian	I-24	**4.00**	Sinkhole
2	Christian	US 41A	**3.83**	Sinkhole
2	Christian	US 68B	**3.56**	Sinkhole
3	Warren	US 231	**3.54**	Flood
3	Todd	US 79	**3.50**	Sinkhole
3	Warren	US 231	**3.75**	Sinkhole
3	Warren	US 68	**3.75**	Sinkhole
3	Warren	WN 9007	**3.92**	Sinkhole
3	Barren	I-65	**4.00**	Sinkhole
3	Simpson	I-65	**4.00**	Sinkhole
3	Warren	I-65	**4.00**	Sinkhole
3	Warren	I-65	**4.00**	Sinkhole
4	Hardin	US 31W	**3.63**	Flood
4	Hardin	I-65	**3.87**	Flood
4	Hardin	I-65	**3.67**	Sinkhole
4	Hardin	US 31W	**3.67**	Sinkhole
4	Hardin	WK 9001	**3.72**	Sinkhole
4	Hardin	I-65	**3.89**	Sinkhole
4	Hart	I-65	**4.00**	Sinkhole
4	Larue	I-65	**4.00**	Sinkhole
5	Jefferson	US-31W	**3.54**	Flood
6	Campbell	I-275	**3.54**	Flood
6	Kenton	I-75	**3.54**	Flood
6	Carroll	I-71	**3.62**	Flood
6	Campbell	I- 471	**3.71**	Flood
6	Carroll	I-71	**3.52**	Landslide
6	Gallatin	I-71	**3.52**	Landslide
6	Campbell	KY 9	**3.63**	Landslide
6	Boone	I-275	**3.72**	Landslide
6	Kenton	I-275	**3.73**	Landslide
6	Kenton	I-75	**3.73**	Landslide
6	Campbell	I- 471	**3.80**	Landslide
6	Campbell	I-275	**3.80**	Landslide
7	Montgomery	I-64	**3.52**	Landslide

District	County	Route	Vulnerability Score	Hazard
7	Madison	I-75	**3.80**	Landslide
8	Pulaski	US 27	**3.54**	Flood
8	Casey	US 127	**3.63**	Flood
8	Rockcastle	I-75	**3.71**	Flood
8	Pulaski	US 27	**3.57**	Landslide
8	Rockcastle	I-75	**3.87**	Landslide
8	Pulaski	KY 914	**3.58**	Sinkhole
8	Pulaski	US 27	**3.72**	Sinkhole
9	Rowan	I-64	**3.63**	Landslide
9	Greenup	US 23	**3.70**	Landslide
9	Carter	I-64	**3.72**	Landslide
9	Boyd	I-64	**3.87**	Landslide
10	Perry	KY 80	**3.53**	Landslide
10	Wolfe	KY 9000	**3.53**	Landslide
10	Magoffin	KY 114	**3.58**	Landslide
10	Magoffin	KY 9009	**3.58**	Landslide
10	Magoffin	US 460	**3.60**	Landslide
10	Breathitt	KY 15	**3.67**	Landslide
10	Perry	KY 15	**3.67**	Landslide
10	Wolfe	KY 9009	**3.67**	Landslide
10	Perry	HR 9006	**3.75**	Landslide
11	Whitley	I-75	**3.79**	Flood
11	Knox	US 25E	**3.57**	Landslide
11	Laurel	I-75	**3.67**	Landslide
11	Bell	US 119	**3.68**	Landslide
11	Bell	US 25E	**3.68**	Landslide
11	Harlan	US 119	**3.68**	Landslide
11	Whitley	I-75	**3.87**	Landslide
12	Knott	KY 15	**3.53**	Landslide
12	Johnson	US 23	**3.60**	Landslide
12	Knott	KY 80	**3.60**	Landslide
12	Lawrence	US 23	**3.60**	Landslide
12	Letcher	US 119	**3.62**	Landslide
12	Pike	US 23	**3.62**	Landslide
12	Pike	US 460	**3.62**	Landslide
12	Floyd	KY 114	**3.68**	Landslide
12	Floyd	KY 80	**3.68**	Landslide
12	Pike	US 119	**3.77**	Landslide
12	Pike	US 23	**3.78**	Landslide
12	Floyd	US 23	**3.83**	Landslide

Data generated from the VAST assessment and from the district workshops resulted in a GIS database of transportation assets that includes the prioritized ranking of vulnerabilities derived from the keypad exercises, local expert knowledge on historical vulnerabilities elicited from the workshops, and other relevant vulnerability data gathered from available data sources. This resulting geodatabase is designed to serve as an easily accessible inventory of natural hazard risk and vulnerabilities for Kentucky's NHS.

The VAST assessment is designed solely to be a screening tool for identifying vulnerability across a large number of assets. For assets with high vulnerability scores, further individual and in-depth analysis is required to determine asset-specific vulnerability. Additionally, the VAST analysis should be interpreted as the first of multiple iterations to be conducted as new indicator datasets are identified and existing datasets are refined and updated.

1.6.4. Secondary Results

This research produced large amounts of data and information from the workshops and data gathering phases. Secondary results beyond those captured in the VAST analysis are also worth noting. Near the completion of each of the district workshops, participants were asked to identify the worst case plausible scenario for the district's transportation system, in terms of natural hazards. For some districts, the worst case scenario centered on a particular hazard. For example, workshop participants in Districts 1 and 2 identified a major earthquake as being the worst case scenario. For other districts, the worst case scenario centered on a particular asset critical to the transportation system. For example, District 7 identified the I-75 Clays Ferry Bridge over the Kentucky River as being extremely critical, though not particularly vulnerable to any of the hazards. The worst case scenarios identified in the workshops for each of the districts are included below. Each of these worst case scenarios are described in more detail in each of the respective district assessments (subsequent chapters).

- Districts 1 and 2: Major earthquake knocking out bridge or dam
- Districts 3 and 4: I-65 sinkhole
- District 5: Ohio River flood that closes bridges
- District 6: Flood/landslide that closes any Ohio River bridge
- District 7: Clays Ferry Bridge closure
- District 8: I-75 / US-25 (detour route) closing simultaneously
- District 9: I-64 closure, particularly at bridge over Big Sandy River
- District 10: Flood/landslide closing Mountain Pkwy
- District 11: Flood/landslide closing I-75
- District 12: Flood/landslide closing US-23 or US-119

Other findings from the workshop discussions pertained to external factors affecting natural hazard vulnerability. Examples of such issues include land use changes, waterway maintenance issues outside of the right of way, debris clogging drains and pipes, and karst-related flooding. In some cases, workshop participants identified communities or critical facilities that had been cut off due to flooded roads. These findings are also presented for each of the respective district assessments.

1.7.Discussion

The vulnerability assessment gathered and documented extensive data regarding asset vulnerability to extreme weather and natural hazards. Information gathered to establish risk and vulnerability during the assessment is now being utilized to develop a risk-based asset management plan on the NHS, as required by MAP-21. As a part of this asset management plan, strategies are being developed to help mitigate the effects from extreme weather and natural hazards on NHS transportation assets. These strategies are being integrated into KYTC's planning, design, and maintenance efforts. Design mitigation strategies may include implementing enhanced design standards or utilizing construction techniques or materials that make an asset more resilient to the effects from extreme weather and natural hazards. Maintenance mitigation activities may include removing debris flows near structures on a regular basis or placing protective fencing adjacent to roadway where rock falls occur regularly. These mitigation strategies can be specific to the hazard or hazards that pose the greatest threat to NHS assets for specific areas of the state identified during the District workshops. For instance, mitigation in the western part of the state will focus more on seismic and flooding hazards while the northern part of the state will focus on landslides and freeze-thaw cycles. Additionally, as part of the asset management plan, cost-benefit analyses will be developed and performed to determine whether the proposed mitigation strategies are cost effective for implementation.

Identifying and resolving vulnerabilities was the primary goal of this vulnerability assessment. Vulnerability assessments identify facets of exposure in the transportation system that could be addressed through policy or infrastructure enhancements. They also provide decision makers with information on where the transportation system's resiliency could be improved. With this knowledge, decision makers can be more proactive in addressing issues related to transportation vulnerabilities. These assessments illuminate potential issues before they result in a major incidents or closures. Drawing on information from these assessments will create a more up-to-date and well-maintained transportation system by helping officials identify and resolve issues before they grow and become unmanageable. Additionally, conducting and acting upon vulnerability assessments reduces financial losses that would occur if the system were to fail completely. Maintaining a secure and safe transportation system mitigates negative publicity that may arise were the system to fail.

2. KYTC District 2

2.1.District Overview

KYTC District 2 is located in western Kentucky and encompasses the counties of Caldwell, Christian, Daviess, Hancock, Henderson, Hopkins, McLean, Muhlenberg, Ohio, Union, and Webster. At the north end of District 2 is the Ohio River and the cities of Owensboro and Henderson. At the south end of the district on the border with Tennessee is Fort Campbell, with the city of Hopkinsville located nearby. The majority of District 2 lies in the Western Kentucky Coalfield geological region, while the southern and western areas of Christian and Caldwell counties are located in the Pennyroyal geological region.

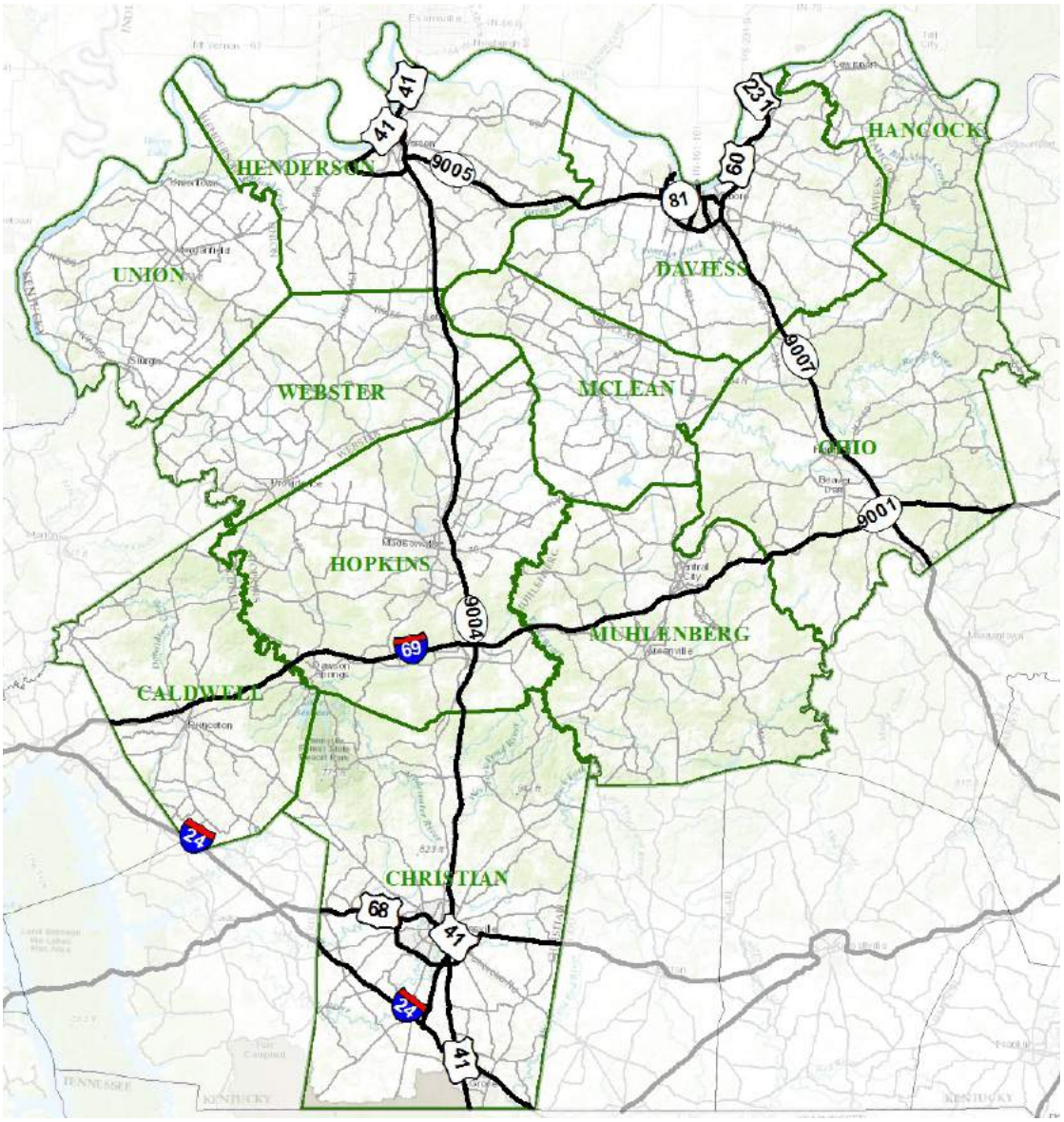


Figure 2-1. KYTC District 2 NHS

The NHS in KYTC District 2 is comprised of 747 centerline miles of roadway (for divided highways, centerline miles are doubled in this total). District 2 interstates include I-24 and the recently appointed I-69. Parkways include the Western Kentucky Parkway (WK-9001), the Pennyrile Parkway (EB-9004), the Audubon Parkway (AU-9005), and the Natcher Parkway (WN-9007). US Highways that are a part of the NHS in the district include US-41, US-60, US-68, and US-231. Additional NHS assets in District 2 include 121 bridges, 22 culvert locations, and 199 other structures. Major NHS bridges over the Ohio River include the US-41 Twin Bridges north of Henderson, the KY-2262 Glover Cary Bridge in Owensboro, and the US-231 William H. Natcher Bridge northeast of Owensboro.

2.2.Hazards

District 2 NHS assets, including highway segments, bridges, culverts, and other structures were assessed against the four primary hazards identified for this project: earthquake, flood, sinkhole, and landslide. Table 2-1 summarizes the relationship between these NHS assets and selected natural hazard indicators.

Table 2-1. Summary of KYTC District 2 NHS assets and natural hazard indicators

Asset Type	D2 Total	PGA ≥ 60 (Destructive)	PGA ≥ 30 and < 60 (Very Strong)	PGA ≥ 18 and < 30 (Strong)	In Flood Plain	Major Karst	Moderate Karst	High Landslide Susceptibility	Moderate Landslide Susceptibility
Total Road Miles	747	0	83	571	35	207	33	0	136
Interstate	231	0	39	192	7	82	8	0	14
Parkway	316	0	5	218	13	34	25	0	60
US Highway	177	0	32	144	15	90	0	0	39
KY Routes	23	0	6	17	0	0	0	0	22
Local Road	0	0	0	0	0	0	0	0	0
Bridges	121	0	11	100	85	29	0	0	19
Culverts	22	0	5	14	19	7	2	0	2
Structures	199	0	29	147	1	46	9	0	44

2.2.1. Earthquake

District 2 lies in close proximity to both the New Madrid Seismic Zone, centered on the Mississippi River, and the Wabash Valley Seismic Zone, centered on the Wabash River in Indiana and Illinois. Figure 2-2 locates District 2 relative to United States Geologic Survey (USGS) defined Peak Ground Acceleration (PGA) Zones. PGA is a measure of the Earth's movement at a given location as a result of seismic activity. It accounts for the amount of energy released by an earthquake and how this energy travels through varying types of soil and rock. PGA is expressed as a percent of gravity (%g) with 2% probability of exceedance in 50 years.

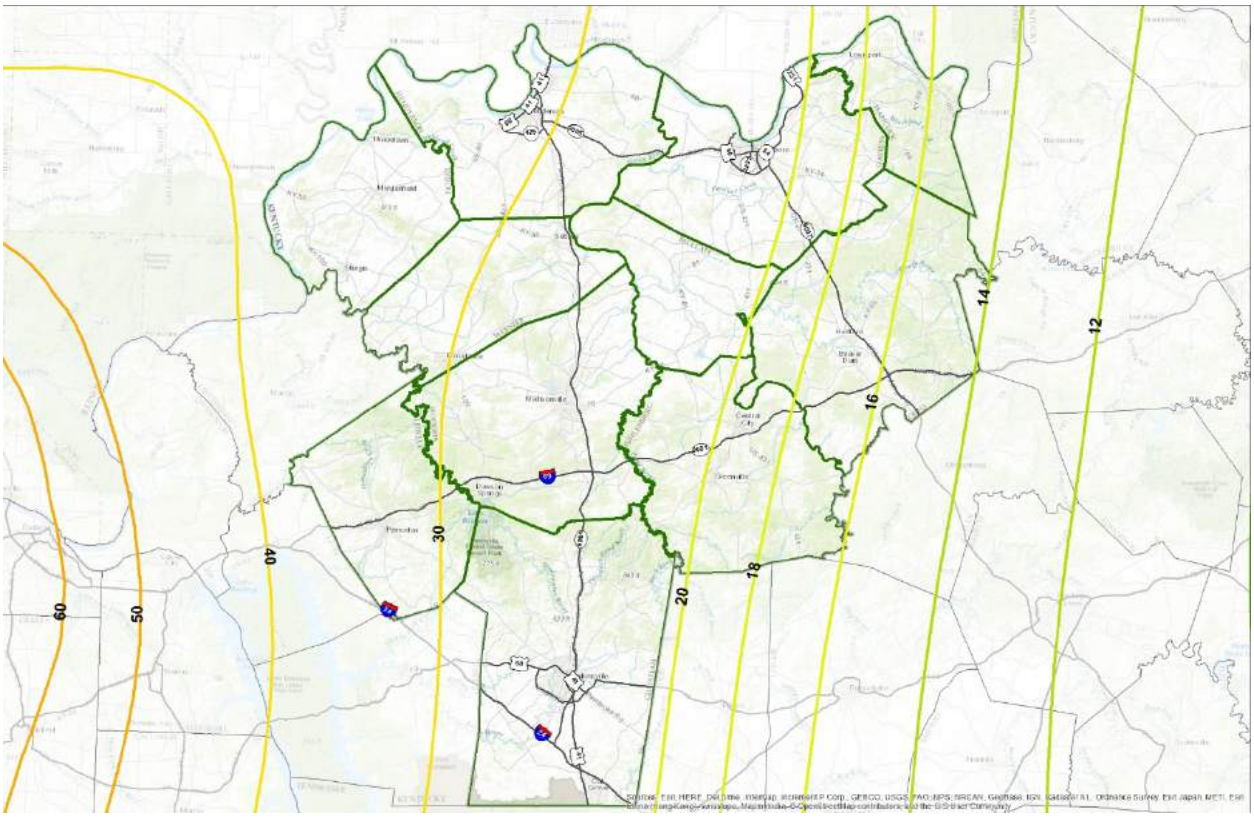


Figure 2-2.USGS PGA zones in KYTC District 2

District 2 lies within PGA zones ranging from 14 to 30. A PGA rating of 18 to 34 roughly equates to "Very Strong" on the Modified Mercalli Scale, and is described as "Mild alarm; walls crack; plaster falls." A PGA rating of 9 to 18 roughly equates to "Strong" on the Modified Mercalli Scale, and is described as "Trees sway; suspended objects swing; objects fall off shelves." District 2 NHS assets lying in PGA Zone 30 include the US-41 Twin Bridges; US-60, US-41A, and KY-425 in the city of Henderson; and I-69 in Caldwell County. The majority of District 2 NHS assets lie in PGA Zones 18 and 20, including I-69, I-24, Audubon Parkway, Pennyrile Parkway, portions of the Western Kentucky Parkway and Natcher Parkway, US-68, US-41, as well as all NHS assets in Owensboro and Hopkinsville.

2.2.2. Flood

A considerably large area of District 2 is in the 100-year floodplain (Figure 2-3). The floodplain along the Ohio River is as wide as 7 miles in places, and is also wide along the Green River, Tradewater River, and Pond River. The southern counties of District 2 have less area in the 100-year floodplain due to the karst topography and absence of major rivers. In all, District 2 has 35 centerline miles of NHS roadway located in the 100-year floodplain. Other NHS assets located in the 100-year floodplain are 85 bridges, 19 culverts, and one other structure.

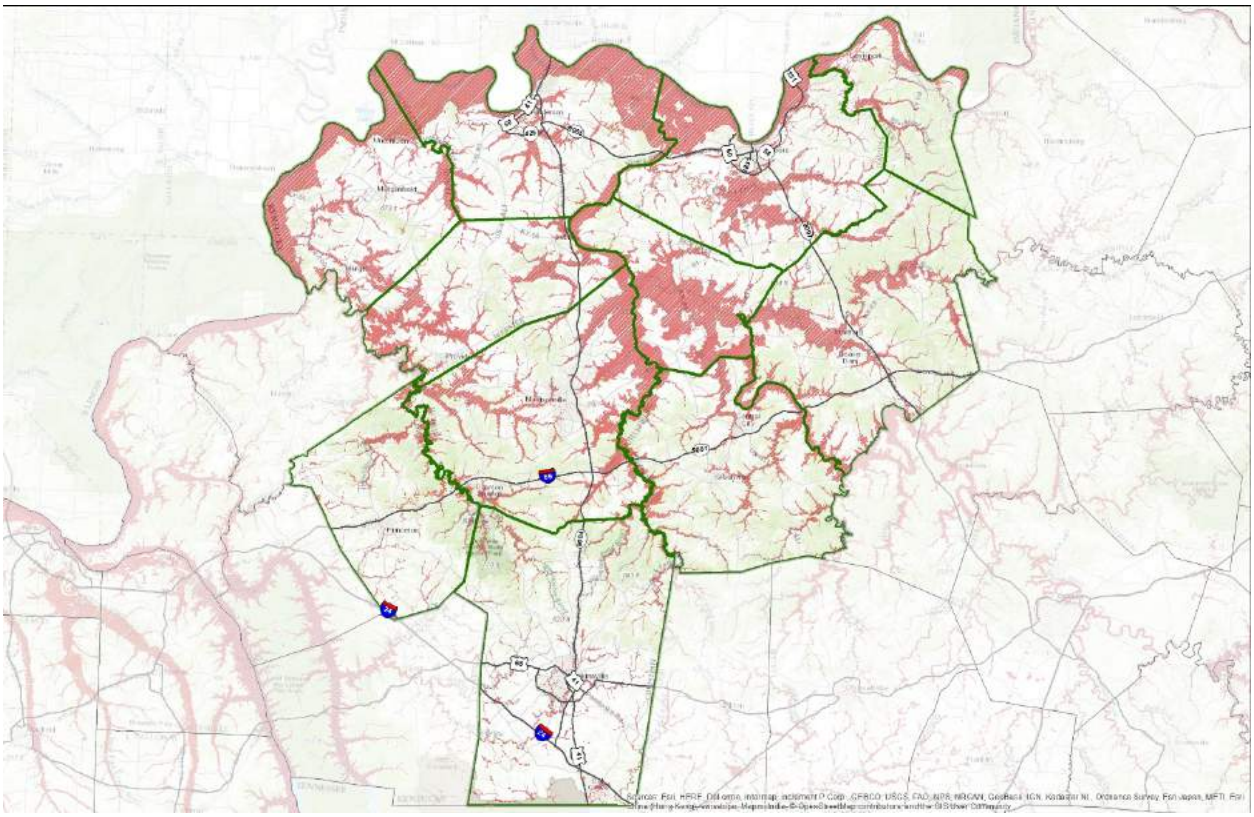


Figure 2-3. KYTC District 2; location of 100-year floodplain

Compared to the rest of the state, the western parts of Kentucky, including KYTC Districts 1, 2, and 3 have experienced more extreme rainfall events (greater than 3" of rain in a single calendar day) than other districts. District 2 experienced such extreme rainfall events on average every 2-3 years from 1981 to 2015, compared to parts of eastern Kentucky that experienced such rainfall events every 10 years or more.

2.2.3. Landslide

Due to the relatively flat topography of District 2, landslide is not a major hazard. Figure 2-4 is a map that depicts the landslide incidence and susceptibility in District 2. Landslide susceptibility here is defined as the probable degree of response of rocks and soils to natural or artificial cutting or loading of slopes, or to anomalously high precipitation. Landslide incidences are those documented as part of the Kentucky Geological Survey (KGS) Landslide Inventory. Figure 2-4 shows some landslide susceptibility to NHS assets located between the cities of Henderson and Owensboro. KGS documented landslides include those on the Audubon Parkway, I-69 in Caldwell

County, the Western Kentucky Parkway in Muhlenberg and Ohio Counties, and I-24 in Christian County.

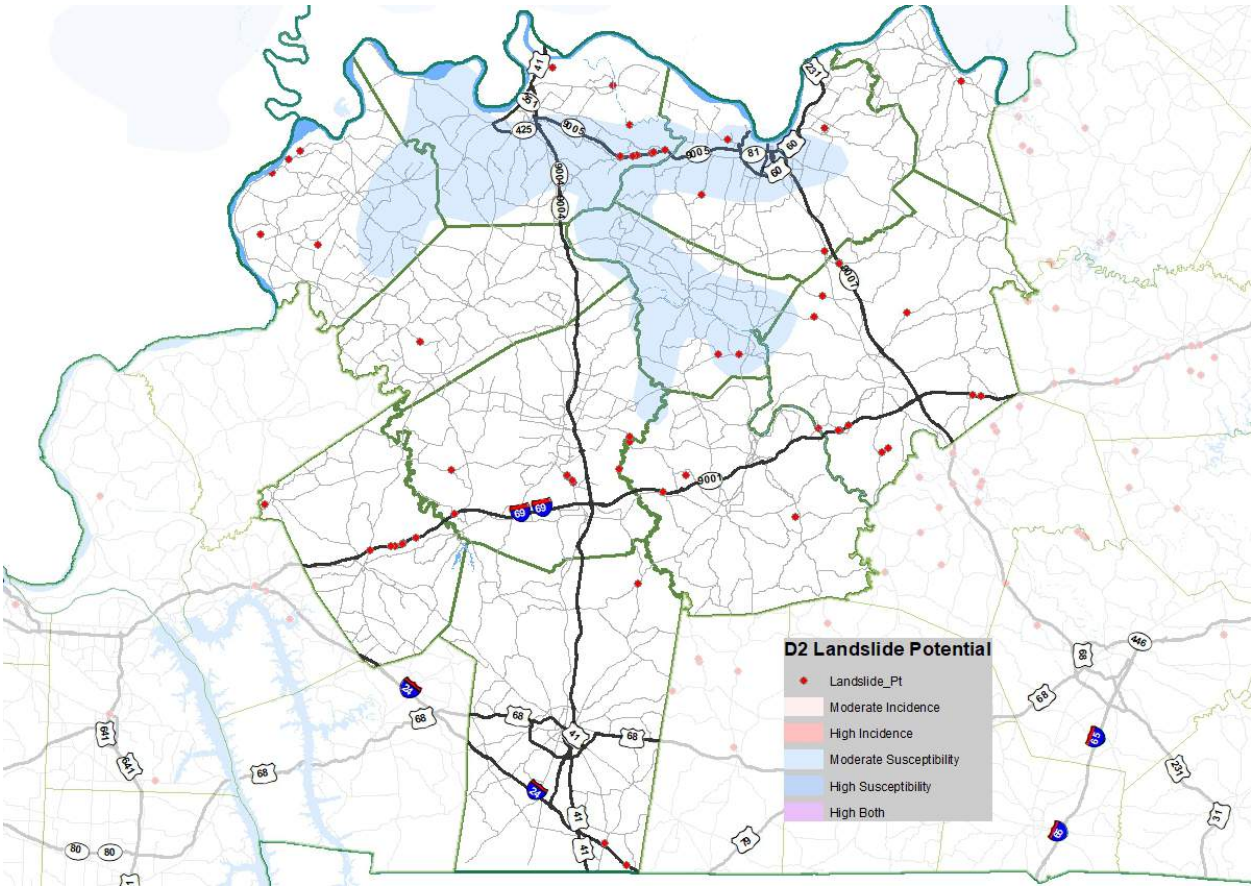


Figure 2-4. KYTC District 2 documented landslides and landslide susceptibility

Within the KGS landslide inventory database, landslides have been documented at the following locations along the NHS:

- Heavy rainfall landslide on US 41 North near Audubon Park; Henderson County.
- Three embankment landslide corrections on Audubon Parkway (KY 9005) at MPs 13.4, 13.5, 13.8; Henderson County.
- Landslide on KY 416 MP 16.8, SW corner of Audubon Parkway; Henderson County
- Embankment slope failures at KY 416 & Audubon Parkway Interchange between MP 10 and 11; Henderson County.
- Landslide correction on AU 9005 MP 11.96; Henderson County.
- Landslide KY 416 over Audubon Parkway at MP 10-11; Henderson County.
- Small slump in loess road embankment on AU 9005 MP 15; Henderson County.
- Slumping below roadway on AU 9005 MP 11.45, mine subsidence or the water going through the embankment could be bleeding into the old mine and taking fines with it; Henderson County.
- Landslide on Audubon Parkway, shallow, small slide on slope near exit ramp; Daviess County.

- Landslide correction on WN 9007 at MP 58.2; Ohio County.
- Rockfall observed while driving westbound on WK 9001 MP 68; Ohio County.
- Embankment landslide corrections on WK 9001 at MP 83 (eastbound and westbound), MP 83.4 EB, MP 84.4 WB; Ohio County.
- Landslide Correction on KY 9001 at MP 67.5 WB and MP 67.35; Ohio County.
- Embankment failure on WK 9001 at MP 46.5 WB; Muhlenberg County.
- Landslide I-69 Western Kentucky Parkway MP 23.4 westbound land; Hopkins County.
- Landslide above roadway I-69 MP 15; Caldwell County.
- Landslide WK Parkway MP 13.2; Caldwell County.
- Landslide WK Parkway MP 16.975; Caldwell County.
- Landslide WK Parkway MP 17 (westbound lanes); Caldwell County.
- Road embankment failure I-69 MP 15.6; Caldwell County.
- Landslide WK Parkway MP 16.9 and MP 18.5; Caldwell County.
- Landslide I-24 roadside rest area MP 92; Christian County.

2.2.4. Karst

Karst topography is present in the southern part of District 2, particularly in Christian and Caldwell Counties. All NHS assets in these two counties, including I-69 in Caldwell County, I-24, Pennyrile Parkway, US-41, US-41A, US-68, and US-68B in Christian County, are located in areas of high karst potential and are vulnerable to sinkhole formation (Figure 2-5). Outside of these two counties in District 2, sinkholes are not commonly found.

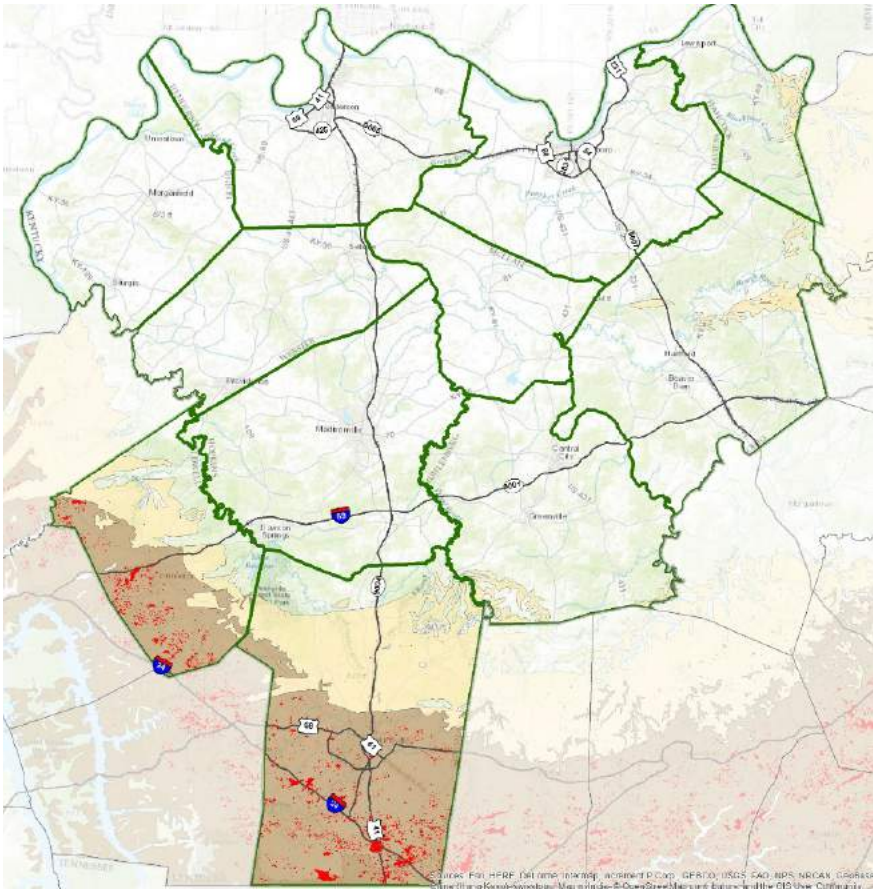


Figure 2-5. Karst potential and sinkholes in KYTC District 2

In all, there are 207 miles of District 2 roadway, as well as 29 bridges, 7 culverts, and 46 structures that are located in a high karst potential area. Numerous sinkholes documented by KGS are located along I-24 in Christian County, including ones at mile markers 71, 74.8, 75.7, 76, 76.6, 80.6, 84.4, 87.2, 89, 89.6, and 93.3. Additionally, the interchanges between I-24 and the Pennyrile Parkway, and between I-24 and US-41 are both located adjacent to or within major sinkholes.

2.2.5. Other Meteorological Hazards

- Snow/Ice: District 2 averages 12" or less of annual snowfall, with the southern areas averaging less than 10" and the northern areas averaging closer to 12". Most of western and southern Kentucky lie within the 6" to 12" range, which is a lower annual snowfall than the state average.
- Freeze/thaw: District 2 has fewer than average annual number of freeze/thaw days compared to the rest of the state. Counties in the district averaged 71-75 freeze/thaw days annually between 1981 and 2015, compared to the overall state average of 84.
- Extreme heat: Within the state, KYTC Districts 1 and 2 suffer on average the most extreme heat events. Counties in District 2 averaged between 6 to 9 annual days between 1981 and 2015 where the maximum temperature exceeded 95 degrees Fahrenheit. Hopkins County had the highest annual average in the district and second highest in the state at 9.2. The statewide average was just under 4.

- Drought/wildfire: Within the state, wildfire outbreaks are most common in southeastern Kentucky. From 2002-2015, USGS documented only thirteen wildfire events in District 2, all of which were minor in scale: two near the Natcher Parkway in Ohio County, six near the Western Kentucky Parkway in Muhlenberg and Ohio Counties, four near I-69 around Madisonville, and one near I-24 west of Hopkinsville.
- Tornado: Of the 12 KYTC Districts in Kentucky, District 2 is the most vulnerable to tornadoes. From 1951 to 2015, District 2 experienced both the most overall tornadoes (115) and the most F3 to F5 tornadoes (27) in Kentucky. The twenty-seven F3 to F5 tornadoes were nearly twice as many as any other KYTC district.

2.3.Workshop

The research team conducted a facilitated workshop in District 2 in August 2016. The workshop was held to gather local district knowledge regarding the effects of natural hazards to KYTC NHS assets in District 2. Thirteen KYTC District 2 personnel attended the workshop. During the three hour workshop, data was collected from participants through a series of facilitated events, including: 1) two keypad exercises where participants were asked to score the criticality of the roadway and the potential impacts of an extreme weather and/or natural hazard event, 2) a mapping exercise with a focused conversation to contextualize flooding events in the District, and 3) a consensus workshop where participants identified and discussed challenges to performing transportation system maintenance.

2.3.1. Polling Results

The NHS in District 2 was divided into 28 segments based upon road designation and county location. Workshop participants were provided with keypads and asked to evaluate each of the NHS segments for criticality and potential impacts from extreme weather and natural hazards. An overall vulnerability score for each segment was computed by multiplying together the criticality and impacts ratings. The vulnerability score represents a metric for identifying highway segments that are both the most important and that could potentially suffer the most damage from natural hazards. Table 2-2 displays the results of the workshop keypad assessments. The final column ranks each segment by the vulnerability score.

Table 2-2. District 2 workshop polling results showing criticality, impacts, and vulnerability

Segment ID	County	Segment Description	Criticality	Impacts	Vulnerability	Rank
1	Henderson	US 41-Ohio River bridge and approach from Henderson	9.0	8.9	80.1	1
2	Henderson	US 60/US 41A-Henderson	5.6	6.3	34.9	22
3	Henderson	KY 425-Henderson	5.4	5.9	32.0	23
4	Henderson	Audubon Parkway-Henderson County	6.9	7.7	53.4	8
5	Henderson	I-69-Henderson County	7.8	6.0	47.0	16
6	Daviess	US 231-Ohio River bridge and approach northeast of Owensboro	5.9	5.0	29.5	25
7	Daviess	US 60-Owensboro	7.5	6.3	47.3	15
8	Daviess	KY 331/CS 1060- Owensboro Riverport access	4.9	4.3	21.0	28
9	Daviess	KY 2262-Ohio River bridge in Owensboro	7.5	7.5	56.3	5
10	Daviess	Audubon Parkway-Daviess County	7.1	7.2	50.8	10
11	Daviess	KY 81/KY 54-Owensboro	6.5	4.6	30.1	24
12	Daviess	KY 2155- Owensboro	5.3	4.7	24.9	27
13	Daviess	KY 2831- Owensboro	6.3	4.2	26.5	26
14	Daviess	Natcher Parkway- Daviess Cty	7.9	5.5	43.2	20
15	Webster	I-69- Webster Cty	7.4	6.9	50.7	11
16	Ohio	Natcher Parkway- Ohio Cty	7.5	6.0	45.2	18
17	Ohio	Western KY Parkway- Ohio Cty	7.8	8.1	63.0	3
20	Hopkins	I-69- Hopkins Cty north of KY 2171	7.3	5.5	40.0	21
19	Muhlenberg/ Hopkins	Western KY Parkway- Muhlenberg/Hopkins Cty	7.3	7.5	55.3	6
18	Hopkins	I-69- Hopkins Cty south of KY 2171	7.5	6.6	49.2	13
21	Caldwell	I-69- Caldwell Cty	7.7	6.9	53.3	9

22	Hopkins/ Christian	Pennyrile Parkway- from I-69 (Hopkins Cty) to KY 1682 (Christian Cty)	7.3	6.4	46.9	17
23	Christian	US 68/US 41- Hopkinsville and Christian Cty	7.5	6.4	47.8	14
24	Christian	US 68B- Hopkinsville	7.8	6.3	49.4	12
25	Christian	I-24- Christian Cty	8.9	8.3	74.2	2
26	Christian	US 41A- Christian Cty	7.8	5.6	43.9	19
27	Christian	Pennyrile Parkway- from I-24 to KY 1682 Christian Cty	7.2	7.7	55.2	7
28	Caldwell	I-24- Caldwell Cty	8.0	7.1	57.0	4

2.3.2. Map Exercise

Workshop participants were asked to review and mark-up eight detailed maps of the NHS in District 2. The maps included NHS roadway segments and the associated bridges, culverts, and other structures; other state highways; streams, rivers, and other bodies of water; and the 100-year floodplain. Participants were asked to mark the maps and provide as much detail as possible for areas along the NHS that have 1) flooded in the past, or 2) have been close to flooding in the past. Table 2-3 displays the results of this exercise.

Table 2-3. District 2 NHS segments and flood

District	County	MP	Route	Hazard	Intersecting feature
2	Henderson	15.02	US-41	Has flooded	N Fork Canoe Creek
2	Henderson	19.15	US-41	Has flooded	Mound Slough/Ohio River
2	Henderson	10.05	US-60	Has flooded	Canoe Creek
2	Henderson	3.47	KY-425	Has flooded	Elam ditch
2	Henderson	1.7	KY-425	Has nearly flooded	Wilson Creek
2	Henderson	2.84	KY-425	Has nearly flooded	Canoe Creek
2	Henderson	6.22	AU-9005	Has nearly flooded	Lick Creek
2	Henderson	15.8	AU-9005	Has nearly flooded	Green River/Daviess Border
2	Henderson	143.3	I—69	Has flooded	Elam ditch
2	Daviess	13.2	US-231	Has nearly flooded	Ohio River 100-year Floodplain
2	Daviess	25.15	US-60	Has nearly flooded	Pup Creek in Ohio River FP
2	Daviess	27.37	US-60	Has nearly flooded	Kelly Creek in Ohio River FP
2	Daviess	0	US-60	Has flooded	Rhodes Creek
2	Daviess	0	KY-81	Has flooded	Downtown Owensboro
2	Daviess	0.63	KY-2155	Has flooded	Horse Fork
2	Daviess	0	KY-2831	Has flooded	Downtown Owensboro
2	Daviess	69.52	WN-9007	Has flooded	N Fork Panther Creek
2	Christian	3.2	US-68	Has flooded	Sinking Fork
2	Christian	4.7	US-68	Has flooded	Muddy Fork
2	Christian	10.75	US-68	Has flooded	North Fork Little River
2	Christian	11.4	US-41	Has flooded	South Fork Little River
2	Christian	10.05	US-68	Has nearly flooded	Tributary of North Fork Little River

District	County	MP	Route	Hazard	Intersecting feature
2	Christian	9.2	US-68	Has nearly flooded	Tributary or backwater of North fork Little River
2	Christian	17.2	US-68	Has flooded	Ephemeral Drainage to South Fork Little River
2	Christian	18.2	US-68	Has flooded	South Fork Little River
2	Christian	14.6	US-68	Has nearly flooded	Tributary of South Fork Little River
2	Christian	21.1	US-68	Has nearly flooded	At border of Todd County
2	Christian	6.1	US-68B	Has flooded	South Fork Little River
2	Christian	3.8	US-68B	Has flooded	North Fork Little River
2	Christian	10.4	US-68B	Has flooded	South Fork Little River
2	Christian	6.5	US-68B	Has nearly flooded	Underpass at Pennyrile Parkway and Little River Trib
2	Christian	6.7	US-68B	Has nearly flooded	Tributary of Little River
2	Christian	7.8	US-68B	Has nearly flooded	Tributary of South Fork Little River West of KY -0109
2	Christian	8.75	US-68B	Has nearly flooded	At KY-0109
2	Christian	70.55	I—24	Has flooded	Sinking Fork
2	Christian	78.95	I—24	Has flooded	Little River
2	Christian	91.4	I—24	Has flooded	West Fork Red River
2	Christian	0.3	EB-9004	Has flooded	Beginning of Pennyrile Parkway
2	Christian	71	I—24	Has nearly flooded	Underpass at KY-0272
2	Christian	92.87	I—24	Has nearly flooded	Far SE of County
2	Christian	80.5	I—24	Has nearly flooded	At KY-0107
2	Christian	82.48	I—24	Has nearly flooded	Bridge around MP 83
2	Christian	14.2	US-41A	Has flooded	South Fork Little River
2	Christian	4.4	US-41A	Has flooded	At I—0024
2	Christian	9.3	US-41A	Has flooded	Tributary of Little River
2	Christian	8.8	US-41A	Has flooded	Near RR tracks
2	Christian	12.7	US-41A	Has nearly flooded	Tributary of Little River
2	Christian	12.3	US-41A	Has nearly flooded	Underpass at RR
2	Christian	15.3	US-41A	Has nearly flooded	Overpass at RR

District	County	MP	Route	Hazard	Intersecting feature
2	Christian	10.9	US-41A	Has nearly flooded	Rock Bridge Branch
2	Christian	8.65	EB-9004	Has flooded	South Fork Little River
2	Christian	19.55	EB-9004	Has nearly flooded	At KY-0107
2	Christian	4.37	EB-9004	Has nearly flooded	Rock Bridge Branch
2	Christian	7.6	EB-9004	Has nearly flooded	Between US-0041A and US-0041

2.3.3. Workshop Discussion

Recurrent roadway flooding emerged as a major theme during the District 2 workshop. As is discussed in some detail below, KYTC District 2 personnel identified multiple state highways that are part of the NHS and other systems that flood on a regular basis. Officials believed land use management to be a major contributor to the recurrent flooding. For example, drainage channels outside of the right of way are often poorly maintained, leading to the build-up of debris and silt. During heavy rain events, this leads to water backing up onto the roadways. Because the problem is occurring outside of the state right of way, special permissions have to be obtained to address the problem. KYTC maintenance officials believe a dedicated program should be established to address these types of problems.

In Christian County, maintenance officials identified land use change as causing flood problems. Land use changes can affect water flow in unanticipated ways, particularly in karst-prone areas. Exit 41A along I-24 has experienced recent flooding, and land use development at the exit is believed to be a major contributor. Specifically, workshop participants attributed the flooding in this area to the intentional filling of a large sinkhole for the construction of a new building in the area.

Several participants also noted that flooding in District 2 is getting worse and attributed that to construction on private property. Participants specifically noted that many farms around the district have built up eight-foot berms creating ditches that are not typically cleaned out. As there is no program to manage privately owned ditches and the process for KYTC employees to help property owners maintain those ditches is administratively difficult, silt builds up and causes flooding on the roadways.

2.3.4. Roadways outside of the NHS that flood

Additional roadways outside the NHS in Henderson County were marked as having flooded in the past. One participant identified the railroad bridge on US-60 as an area that typically floods 2-3 times per year, while others identified US-60 at Seldon, KY as susceptible to flooding. Other areas identified in Henderson County include KY-351, KY-1574, KY-136, KY-2260, KY-283, KY-811, and KY-812. KY-812 was identified as flooding frequently at the bridge approach. Another section of US-60, near KY-812 was marked as close to flooding in the past. Most of the roadways that have flooded in the past or have been close to flooding are located within the 100-year floodplain.

During the map discussion, one participant remarked that during the spring flood of 1997, due to the flooding that occurred on US-431, multiple towns were shut down due to the roads into those towns being flooded for several weeks. Multiple other roadways in the county were also marked as having flooded during the 1997 flood, including KY-81, KY-554, KY-54, and KY-334.

Another participant identified several roadways that were flooded again in 2010, including KY-334 and KY-554. Lastly, several roadways were identified as flooding during heavy rains, including KY-142, where the roadway crosses the North Fork of Panther Creek and KY-762, near the intersection of KY-762 and Boston Laffoon Road. Flood waters were reported to recede after approximately three days.

Several other roadways in Webster County were marked as having previously flooded in 2016. These roads include KY-132, US-41, and KY-138. One workshop participant noted that in 2010, flood waters were so high over the roadways that the City of Clay became an island and was completely cut off from the surrounding areas via the roadway.

In 2016, roadway maintenance became a flooding issue in District 2. On I-24 in Caldwell County, part of the interstate was flooded due to a clogged culvert on the roadway. Once maintenance crews were alerted to the issue, they were able to clear the culvert and the flood waters receded. However, one participant noted that they generally must be reactive rather than proactive in situations such as the one that occurred on I-24 due to the lack of staff available to perform proper maintenance checks.

2.3.5. Maintenance facilities flooding

Several KYTC maintenance facilities have experienced flooding in recent years. At the Muhlenberg County maintenance facility in Central City, one workshop participant stated that during heavy rain events they have to wade through several inches of water when placing "High Water" signs along the roadway. Another participant noted that there was approximately 18 inches of water in the maintenance facility during a July 2016 flood event. This participant did note that draining Cypress Creek, located near the shop, would greatly assist with the flooding problems. Other maintenance facilities in District 2 that have also flooded in the past include the McLean County facility and the salt dome in Christian County.

2.4.Results

2.4.1. Identification of most vulnerable assets

Table 2-4 lists District 2 NHS assets with a vulnerability score of 3.5 or greater for any of the four major hazards in this analysis (a full list of District 2 NHS assets and vulnerability scores is in Appendix 2). Flood and sinkhole are the two hazards that cause the greatest vulnerabilities in District 2. US-41 in Henderson County is scored as having the greatest vulnerability to flooding, while I-24 in Christian County is scored as having the greatest vulnerability to sinkholes. The results of this analysis mirror those from the keypad scoring at the District 2 workshop, where US-41 in Henderson County and I-24 in Christian County were also scored as having the greatest vulnerability. The results differ somewhat in how the Western Kentucky Parkway in Ohio County and Muhlenberg County was scored, in that workshop participants perceived this highway segment to be more vulnerable to flooding than the overall data scoring approach. The Western Kentucky

Parkway along this stretch crosses both the Green River and the Pond River, which likely led workshop participants to perceive the highway as more vulnerable to flooding than what the data suggests.

Table 2-4. District 2 NHS assets with vulnerability score 3.5 or greater

District	County	Route	Vulnerability Score	Hazard
2	Caldwell	I-69	**3.62**	Flood
2	Christian	EB 9004	**3.62**	Flood
2	Christian	I-24	**3.54**	Flood
2	Daviess	AU 9005	**3.71**	Flood
2	Daviess	WN 9007	**3.63**	Flood
2	Henderson	AU 9005	**3.54**	Flood
2	Henderson	I-69	**3.54**	Flood
2	Henderson	US 41	**3.87**	Flood
2	Henderson	US 41A	**3.54**	Flood
2	Hopkins	I-69	**3.71**	Flood
2	Caldwell	I-69	**3.72**	Sinkhole
2	Christian	EB 9004	**3.92**	Sinkhole
2	Christian	I-24	**4.00**	Sinkhole
2	Christian	US 41A	**3.83**	Sinkhole
2	Christian	US 68B	**3.56**	Sinkhole

2.4.2. Worst Case Scenario

Similar to District 1, the worst case plausible scenario for District 2 would be to concurrently experience an Ohio River flood and a major earthquake. The two largest population centers, Owensboro and Henderson, are both located along the Ohio River, and highway segments here are highly vulnerable to river flooding. A major earthquake emanating from the New Madrid Seismic Zone could potentially be severe enough to damage transportation assets in District 2. Combining the two events would impair emergency response efforts, as the Ohio River is a designated emergency seismic response and resupply route and would be unnavigable in the event of a major flood. The NHS asset identified in the workshop as the most vulnerable in the district to such a worse case event was the US 41 bridge over the Ohio River near Henderson, and concerns over both flooding and earthquake contributed to this asset receiving the highest vulnerability ranking.

3. KYTC District 3

3.1.District Overview

KYTC District 3 is located in southwestern Kentucky and encompasses the counties of Allen, Barren, Butler, Edmonson, Logan, Metcalfe, Monroe, Simpson, Todd, and Warren. District 3 is centered on the city of Bowling Green, the largest city in the district and the third largest city in Kentucky. Along the southern end of the district lies the Kentucky border with Tennessee. Major rivers in the district include the Green River, the Nolin River which includes Nolin Lake, and the Barren River which also includes Barren River Lake. The majority of District 3 lies in the Pennyroyal geological region, a karst-prone limestone plain that is dotted with thousands of sinkholes, sinking streams, springs, and caverns. Mammoth Cave, the longest known cave system in the world and a National Park, is located in Edmonson County.

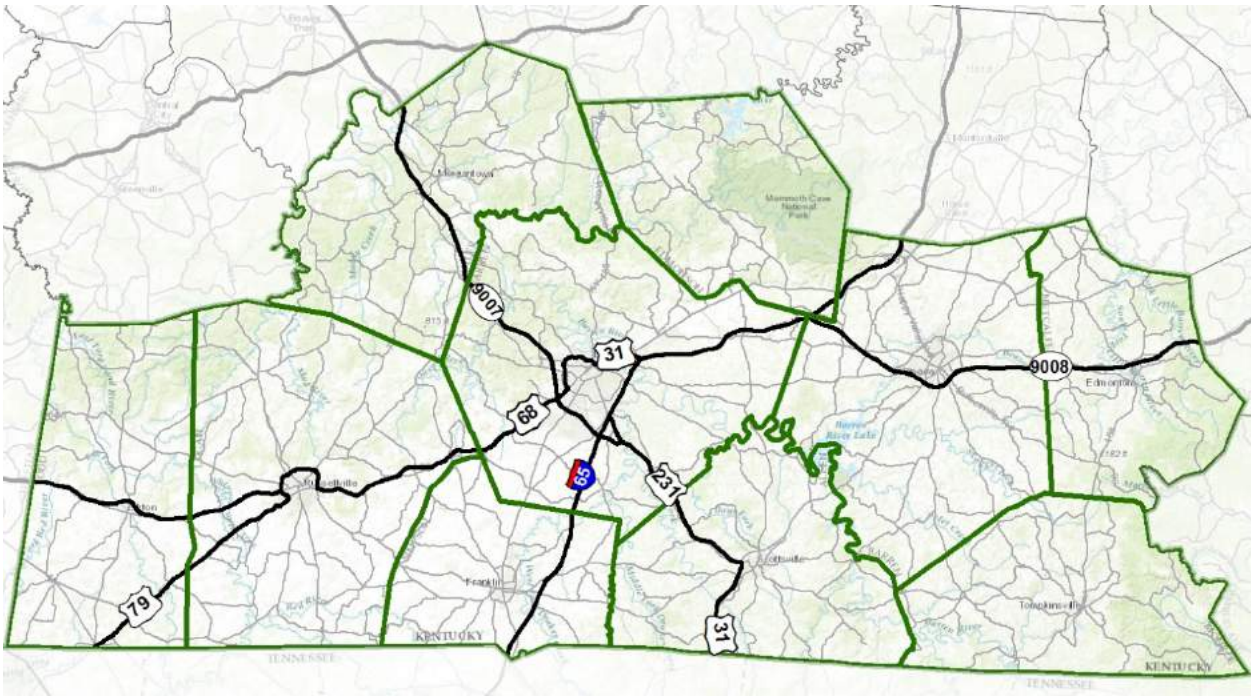


Figure 3-1. KYTC District 3 NHS

The NHS in District 3 is comprised of 492 miles of roadway (for divided highways, centerline miles are doubled in this total). Bisecting the district from north to south is Interstate 65, the most heavily trafficked highway in the district and a major freight corridor of national significance. Parkways include the Natcher Parkway (WN-9007) and the Cumberland Parkway (LN-9008). US Highways that are a part of the NHS include US-31E, US-31W, US-68, US-79, US-231, and US-431. Additional NHS assets in District 3 include 48 bridges, 7 culvert locations, and 79 other structures.

3.2.Hazards

District 3 NHS assets, including highway segments, bridges, culverts, and other structures, were assessed against the four primary hazards identified for this project: earthquake, flood, sinkhole, and landslide. Table 3-1 summarizes the relationship between these NHS assets and the natural hazard indicators.

Table 3-1. Summary of KYTC District 3 NHS assets and natural hazard indicators

Asset Type	D3 Total	PGA ≥ 60 (Destructive)	PGA ≥ 30 and < 60 (Very Strong)	PGA ≥ 18 and < 30 (Strong)	In Flood Plain	Major Karst	Moderate Karst	High Landslide Susceptibility	Moderate Landslide Susceptibility
Total Road Miles	492	0	0	24	15	378	47	0	0
-Interstate	130	0	0	0	1	128	1	0	0
-Parkway	166	0	0	0	4	76	35	0	0
-US	190	0	0	24	10	168	11	0	0
-KY	6	0	0	0	0	6	0	0	0
-Local Road	0	0	0	0	0	0	0	0	0
Bridges	48	0	0	8	39	28	3	0	0
Culverts	7	0	0	1	4	4	0	0	0
Structures	79	0	0	1	0	56	7	0	0

3.2.1. Earthquake

District 3 is moderately close to the New Madrid Seismic Zone, centered on the Mississippi River, and the Wabash Valley Seismic Zone, centered on the Wabash River in Illinois and Indiana. Figure 3-2 shows District 3 relative to USGS defined PGA zones. As Figure 2 illustrates, District 3 lies within PGA Zones 8 to 20. The majority of Todd County is in PGA zones between 18 and 20, which compare on the Modified Mercalli Scale as "Very Strong." This includes most of US-68 and US-79 in Todd County. Logan, Butler, Edmonson, Warren, Simpson, and Allen Counties are in PGA Zones 10 to 16, which compare on the Modified Mercalli Scale as "Strong." NHS assets in these PGA zones include I-65, Natcher Parkway, US-31E, US-31W, US-68, US-79, and US-231. Barren, Metcalfe, and Monroe Counties are in PGA Zone 8, which compares to "Slightly Strong" on the Modified Mercalli Scale.

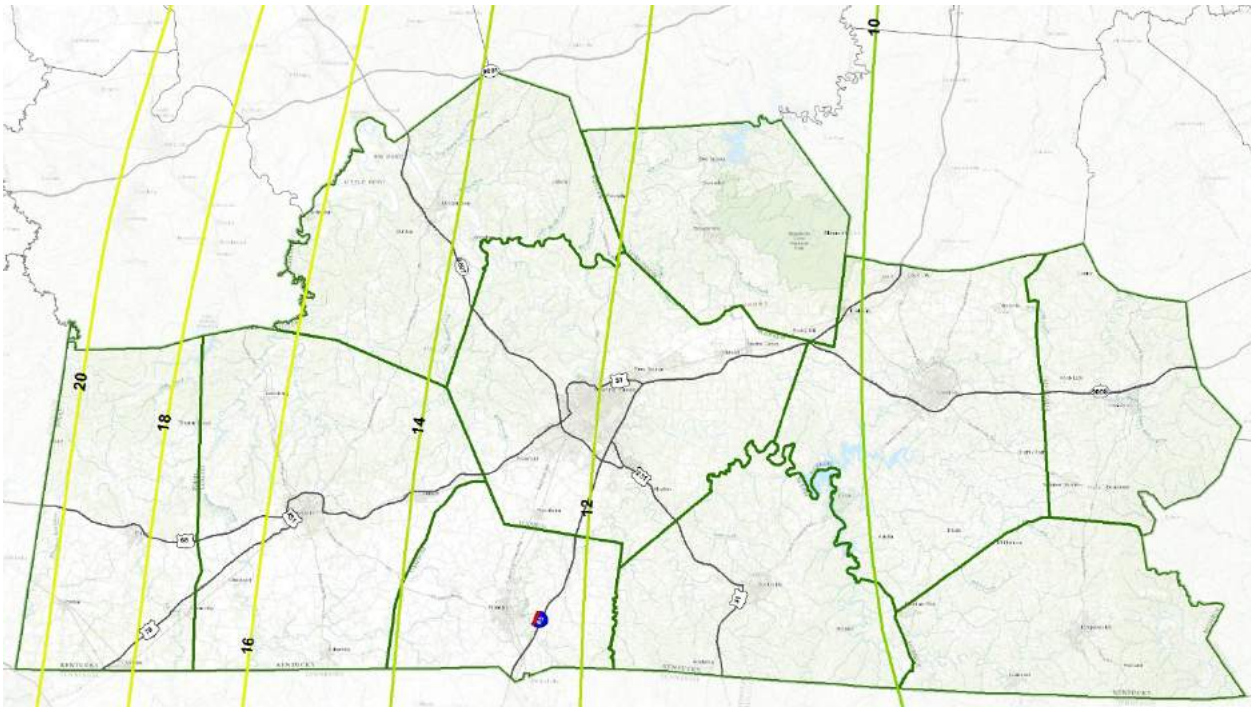


Figure 3-2. USGS PGA zones in KYTC District 3

3.2.2. Flood

Much of District 3 is drained by the Green River system. The Green River flows northward in the District towards the Ohio River and is characterized by a widening 100-year floodplain. The far southeastern and southwestern parts of the district are drained by the Cumberland River system.

Compared to the rest of the state, the western parts of Kentucky, including KYTC Districts 1, 2, and 3 have experienced more extreme rainfall events (greater than 3" of rain in a single calendar day) than other districts. District 3 experienced such extreme rainfall events on average every 2-3 years from 1981 to 2015, compared to parts of eastern Kentucky that experienced such rainfall events every 10 years or more. Extreme rainfall events of this magnitude can result in flash flooding.

In all, District 3 has 15 miles of NHS roadway located in the 100-year floodplain. Other NHS assets located in the 100-year floodplain are 39 bridges and 4 culverts.

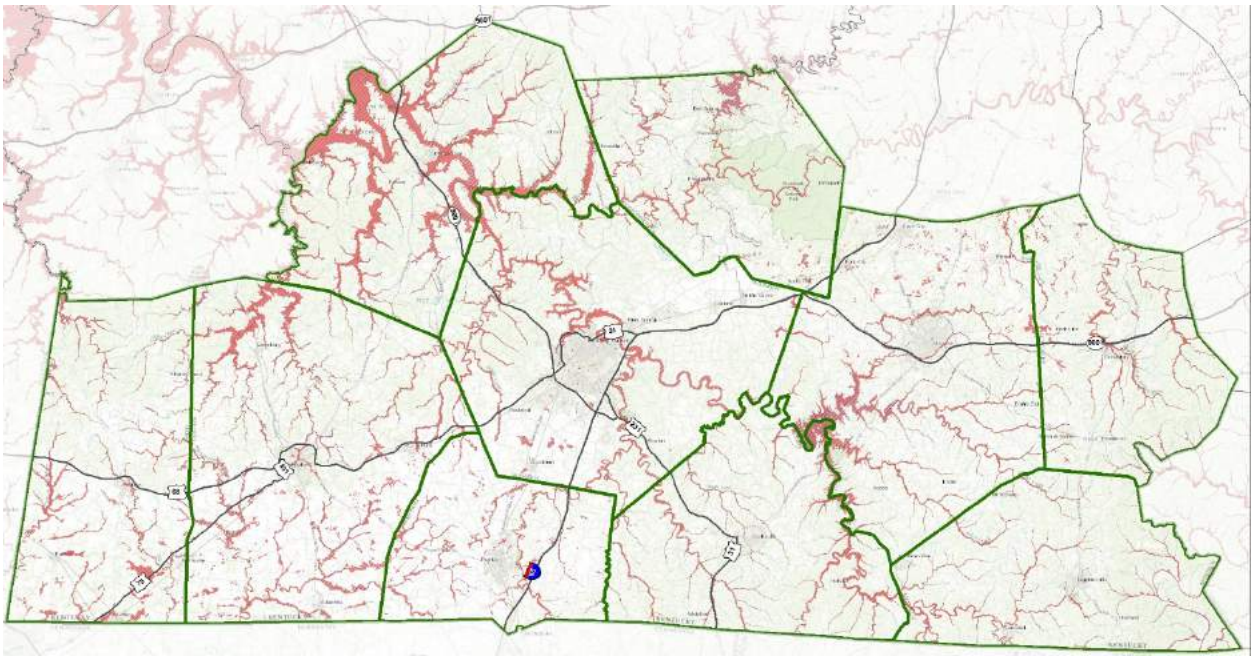


Figure 3-3. KYTC District 3; location of 100-year floodplain

3.2.3. Landslide

The topography of District 3 is relatively flat, therefore, landslide is not a major hazard in the District. As Figure 3-4 depicts, landslide is considered a moderate threat only in the far southeastern part of Monroe County near the Cumberland River. The majority of landslides documented by KGS have occurred in the northern part of the District, particularly Butler County where the Natcher Parkway is located. Three landslides have also been documented along the Cumberland Parkway in Barren and Metcalfe Counties.

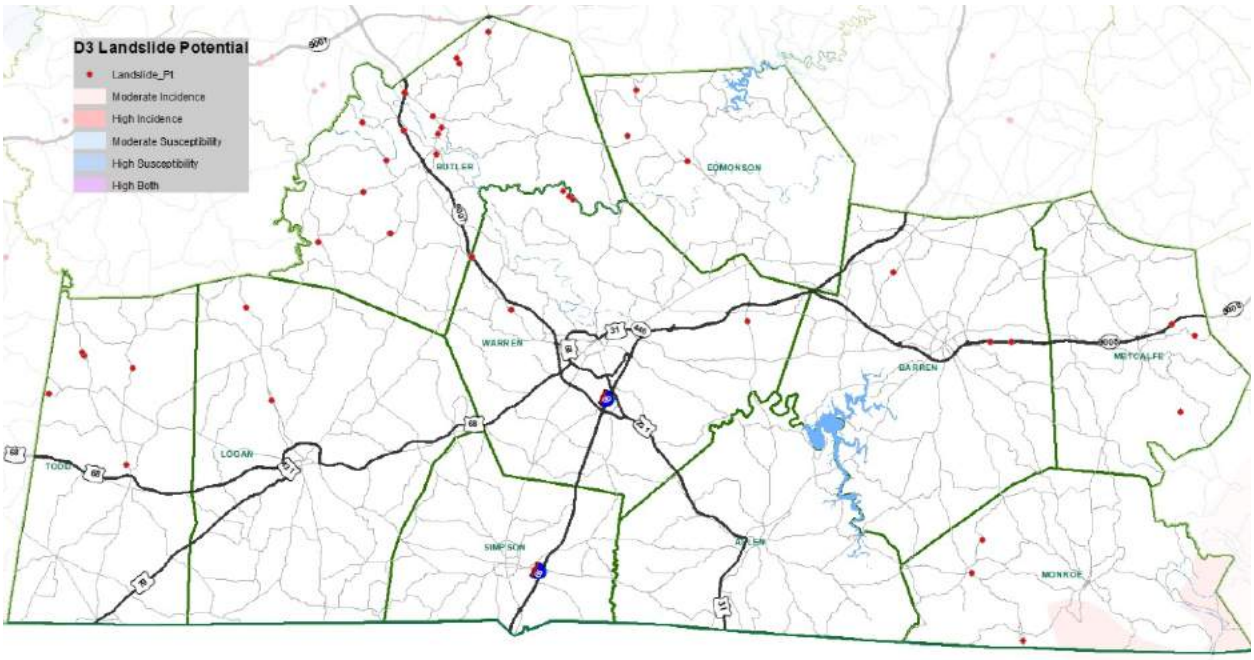


Figure 3-4. KYTC District 3 documented landslides and landslide susceptibility

Within the KGS landslide inventory database, landslides have been documented at the following locations along the NHS:

- Landslide KY 9007 MP 33.845; Butler County.
- Embankment failure KY 9007 MP 30.46 SB; Butler County.
- Landslide on LN 9008 MP 17.35, MP 18.9, and MP 20.65; Barren County.
- Landslide KY 9009 between MP 32 and MP 34; Metcalfe County.
- Landslide KY 9007 MP 18.08; Warren County.

3.2.4. Karst

Sinkholes are a major hazard in District 3. I-65, the most critical NHS asset in the district, runs directly through an area of major karst formation with sinkholes commonly occurring (Figure 3-5). Other NHS assets in karst-prone areas included US-68 and US-79 in Todd and Logan Counties, all NHS assets in and around Bowling Green (i.e., Natcher Parkway, US-31W, US-68, US-231, KY-446), and the Cumberland Parkway in Barren and Metcalfe Counties.

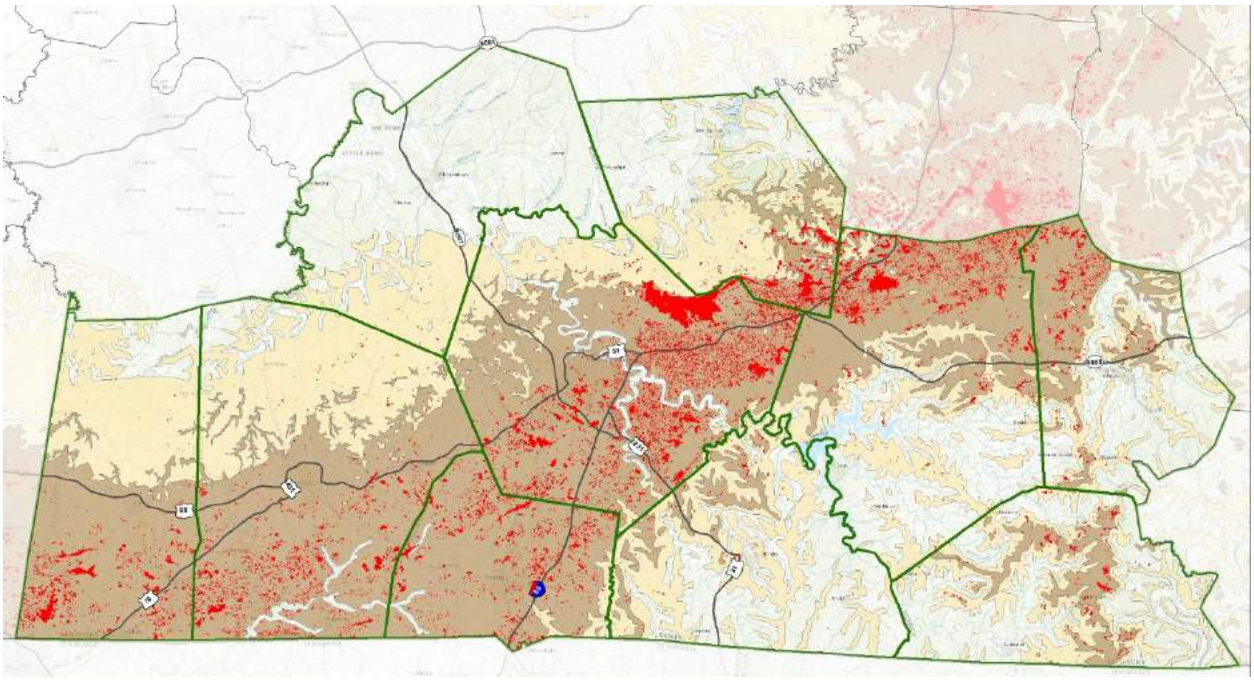


Figure 3-5. Karst potential and sinkholes in KYTC District 3

In all, there are 378 miles of District 3 roadway located in areas of major karst potential, the second most of any KYTC district. Included in this total are 128 interstate miles and 76 parkway miles. Also included are 28 bridges, 4 culverts, and 56 structures located in areas of high karst potential. Numerous KGS-documented sinkholes are located along I-65, to the extent to where nearly every portion of I-65 in the district is located either within or in close proximity to a sinkhole.

3.2.5. Other Meteorological Hazards

- Snow/Ice: Most areas of District 3 average between 8" to 10" of annual snowfall, while the northern parts of the district average 10" to 12". Most of western and southern Kentucky lie within the 8" to 12" range, which is a lower annual snowfall than is averaged in northern and eastern parts of the state.
- Freeze/thaw: The southern counties of District 3 averaged 70-75 freeze/thaw days annually between 1981 and 2015, while the northern counties in the district averaged 75-85. The statewide average was 84 over that time period.
- Extreme heat: District 3 had a higher than statewide average of extreme heat days between 1981 and 2015 where the maximum daily temperature exceeded 95 degrees Fahrenheit. Edmonson County had the highest annual average in the district and ninth highest in the state at 8.2 days, while Metcalfe County had the lowest at 4.1. The statewide annual average from 1981-2015 was 3.8.
- Drought/wildfire: Within the state, wildfire outbreaks are most common in southeastern Kentucky. From 2002-2015, USGS documented five wildfire events in District 3, all of which were minor. One of these was near US-231 west of Bowling Green, one just north of the Cumberland Parkway in Barren County, and three in the far southeastern edge of the district.

- Tornado: Tornado risk in District 3 is slightly higher than in the state overall. From 1951 to 2015, District 3 experienced 66 tornadoes, compared to a KYTC district average of 53, and 11 strong tornadoes (F3 to F5), compared to a KYTC district average of 9.

3.3.Workshop

The research team conducted a facilitated workshop in District 3 in September 2016. Fourteen KYTC personnel attended the workshop. During the workshop, data was collected from participants through a series of facilitated events, including: 1) two keypad exercises where participants were asked to score the criticality of the roadway and the potential impacts of an extreme weather and/or natural hazard event, 2) a mapping exercise with a focused conversation that contextualized flooding events in the District, and 3) a consensus workshop where participants identified and discussed challenges to performing transportation system maintenance.

3.3.1. Polling Results

The NHS in District 3 was divided into 21 segments based upon road designation and county location. Workshop participants were provided with keypads and asked to evaluate each of the NHS segments for criticality and potential impacts from extreme weather and natural hazards. An overall vulnerability score for each segment was computed by multiplying together the criticality and impacts ratings. The vulnerability score, then, provides a metric for identifying highway segments that are both the most important and could potentially suffer the most damage from natural hazards. Table 3-2 displays the results of the workshop keypad assessments. The final column ranks each segment by the vulnerability score.

Table 3-2. District 3 workshop polling results showing criticality, impacts, and vulnerability

Segment ID	County	Segment Description	Criticality	Impacts	Vulnerability	Rank
1	Butler	Natcher Parkway Butler County	6.8	6.3	42.8	11
2	Barren	I-65 Edmonson and Barren County	8.9	7.2	63.3	3
3	Barren	Nunn Parkway west of Glasgow	7.4	6.8	50.3	7
4	Barren	Nunn Parkway east of Glasgow	7.2	7.2	52.1	5
5	Metcalfe	Nunn Parkway Metcalfe County	7.1	6.8	48.3	9
6	Warren	Natcher Parkway northwest of Bowling Green	7.4	6.9	51.4	6
7	Warren	US-68 & US 31W Bowling Green	6.9	7.1	48.6	8
8	Warren	I-65 northeast of Bowling Green	8.6	7.8	67.1	2
9	Warren	I-65 southeast of Bowling Green	8.9	8	70.9	1
10	Warren	US-68 southwest of Bowling Green	6.7	6.9	46.4	10
11	Warren	Natcher Parkway south of Bowling Green	7.1	5.4	38.4	17
12	Warren	US-231 southeast of Bowling Green	6.6	6.4	41.9	13
13	Logan	US-68 east of Russellville	6.2	6.6	41.2	14
14	Logan	US-68 Russellville and west	6.4	6.3	40.1	15
15	Logan	US-79 Logan County	5.8	5.8	33.4	20
16	Todd	US-68 Todd County	6.3	5.8	36.4	18
17	Todd	US-79 Todd County	5.6	6.5	36	19
18	Simpson	I-65 Simpson County	8.9	6.8	60	4
19	Allen	US-231 Allen County	6.6	6.1	39.9	16
20	Allen	US-31E Allen County	6.5	6.5	42	12
21	Warren	KY 880/KY 234: Warren County from I-75 to US 231	6.6	6.4	42.2	14

3.3.2. Map Exercise

Workshop participants were asked to review and mark up eight detailed maps of the NHS in District 3. The maps included NHS roadway segments and the associated bridges, culverts, and other structures; other state highways; streams, riivers, and other bodies of water; and the 100-year floodplain. Participants were asked to mark the maps and provide as much detail as possible for areas along the NHS that have 1) flooded in the past, 2) have been close to flooding in the past, and 3) are likely to flood during an extreme weather event. Table 3-3 displays the results of this exercise.

Table 3-3. District 3 NHS segments and flood

District	County	MP	Route	Hazard	Intersecting feature
3	Warren	5.5	US-231	Has flooded	Drakes Creek
3	Logan	4.65	US-431	Has flooded	Chippoorwill Creek
3	Logan	10.7	US-431	Has flooded	Town Branch
3	Allen	1.97	US-31E	Has flooded	Little Trammel Creek

3.3.3. Workshop Discussion

Workshop participants reported a major flood event that occurred in 2010 that affected Barren, Allen, and Metcalfe Counties. Between May 1 and 2, some of these areas experienced as much as 10” of rainfall, which resulted in widespread flooding and caused $30 million in damages statewide. KYTC maintenance personnel reported multiple roadways that were flooded and in some cases, damaged.

With I-65 being such a critical asset in the district, KYTC maintenance personnel also discussed difficulties with making sure drainage pipes remained clear from debris. With the I-65 widening project complete in the district, officials reported difficulties with checking that the drainage pipes were clear from end to end beneath the highway. They suggested a regular maintenance schedule for the highway with special procedures in place to make sure the interstate drains properly.

3.3.4. Roadways outside of the NHS that flood

Workshop participants identified multiple roadways outside the NHS that are prone to flooding. In Simpson County, several areas were marked as having flooded in the past, including KY 100 and KY 1170. Two areas along KY 100 (MP 2 and MP 16) were identified as flood zones when the area received 2 to 3 inches of rainfall. With 3 inches of rain or more, KY 100 at MP 16 is impassable until the water recedes. The area on KY 1170, just north of Spring Creek, floods with 1 to 2 inches of rain. Along Highway 591, participants discussed that when the county receives 3 or more inches of rain, the roadway becomes impassable. It was identified that due to maintenance issues with one of the drains in that area, the roadway flooded more often than it should.

Multiple roadways in Allen County also experience frequent flooding conditions, including KY 585, which tends to flood every time it rains. The flooding on KY 585 in turn causes flooding on KY 1332. There are also places along US 31E in Allen County where flood waters are close to cresting the roadway from both sides of the embankment. In 2010, there was a significant flood in Allen County, where flood waters covered KY 101 between mile points 4 and 5. The flooding

event in May 2010 also caused flooding issues for other counties in District 3, including Metcalf County, where roads were closed and scour was reported near MP 28. The 2010 flood also caused Whippoorwill Creek to flood the roadway on US 79 in Logan County.

3.3.5. Maintenance facilities flooding

The only KYTC maintenance facility in District 3 that has experienced flooding is the Warren County facility located on the south side of Bowling Green. The entranceway to this facility is next to a creek and along the 100-year floodplain, and KYTC personnel reported past events where the entranceway was impassable due to flooding. During these flood events, an emergency back gate to WN 9007 was used to access the facility.

3.3.6. Consensus workshop

After the discussion of flooding in District 3, participants engaged in a consensus workshop where the following question was posed "What are the Greatest Challenges to Conducting Maintenance in District 3?" Participants were asked to individually brainstorm, discuss their brainstorm ideas with a partner, and share their ideas with the entire group. Table 3-4 shows the final results from the consensus workshop.

Table 3-4. Results of District 3 consensus workshop

Identified Challenges to Conducting Maintenance Operations in District 3						
Keeping Equipment Updated	**Utilities are in the Way**	**Access**	**Expanded Personnel Budgets**	**Funding**	**Better Asset Management and Policy**	**Dealing with the Public**
Keeping Good Equipment and Operators	Proximity of Utilities	Access to the Location of Activity	Lack of Personnel	Money of Materials, Equipment, Rental or Sun-Contract	Upper Management Approval	Ample Space to Work
Equipment and Breakdowns	Utilities	Knowledge of Location	Lack of Needed Manpower Answer: Higher Pay	Funding	Asset Inventory	Debris Disposal Issues
Better Equipment	Utility Coordination Issues	Get Consent from Property Owner	Paperwork: - Evaluations, etc.	Lack of Funding	Need Drainage Inspections on I-65	Property Owner's Agreement
		Clearance from Aerial Utility	Lack of Staff	Funding	Guidance or Policy on When to Inspect	Debris
		Accessibility	Lack of Help	Budget Constraints		
			Personnel: Numbers and Management	Budget		
			People to do Regular Maintenance			

			Need better pay to keep good workers			

3.4.Results

3.4.1. Identification of most vulnerable assets

Table 3-5 lists District 3 NHS assets with a vulnerability score of 3.5 or greater for any of the four major hazards in this analysis (a full list of District 3 NHS assets and vulnerability scores is in Appendix 2). Flood and sinkhole are the two hazards that cause the greatest vulnerabilities in District 2. US-231 in Warren County is scored as having the greatest vulnerability to flooding, while I-65 in Simpson County, Warren County, and Barren County is scored as having the greatest vulnerability to sinkholes. The results of this analysis closely mirror the results from the workshop keypad exercise. In both, the extent of I-65 through the district was scored as the most vulnerable asset in the district.

Table 3-5. District 3 NHS assets with vulnerability score 3.5 or greater

District	County	Route	Vulnerability Score	Hazard
3	Warren	US 231	**3.54**	Flood
3	Todd	US 79	**3.50**	Sinkhole
3	Warren	US 231	**3.75**	Sinkhole
3	Warren	US 68	**3.75**	Sinkhole
3	Warren	WN 9007	**3.92**	Sinkhole
3	Barren	I-65	**4.00**	Sinkhole
3	Simpson	I-65	**4.00**	Sinkhole
3	Warren	I-65	**4.00**	Sinkhole
3	Warren	I-65	**4.00**	Sinkhole

3.4.2. Worst case scenario

The worst case plausible scenario for District 3 would be for a large sinkhole to form underneath I-65 and critically damage the highway. In southern and central Kentucky, I-65 runs through an area of high karst potential with thousands of sinkholes. In 2014, the National Corvette Museum, which is easily visible from I-65 near Bowling Green, made national headlines when a sinkhole opened up underneath the facility, destroying eight cars on display. District 3 workshop participants felt it was not only possible, but even likely, that a similar sinkhole could form under I-65 eventually.

Such an event would have serious consequences for the transportation system in Kentucky and beyond. I-65 is critical to the economy of Kentucky. It serves as a major freight corridor connecting Gulf of Mexico ports with Midwestern markets and manufacturing centers. More freight travels along this corridor than any other in the state. The average annual daily traffic (AADT) on I-65 east of Bowling Green exceeds 50,000. Though US-31W runs roughly parallel to I-65 in southern Kentucky and could be used as an alternative route in an emergency situation, it would not be able to efficiently handle the large numbers of trucks and automobiles over an extended period.

4. KYTC District 4

4.1.District Overview

KYTC District 4 is located in west central Kentucky and encompasses the counties of Breckinridge, Grayson, Green, Hardin, Hart, LaRue, Marion, Meade, Nelson, Taylor, and Washington. The District 4 Office is located in Elizabethtown which is the largest city in the district and the eleventh largest city in the state. District 4 is also home to a large portion of Fort Knox, a 109,000 acre Army Base located in Bullitt, Hardin, and Meade Counties. The Ohio River forms the northeast boundary of the district. Other rivers in the district include Rough River, the Green River including Green River Lake, the Nolin River including Nolin Lake, and Rolling Fork. The majority of District 4 lies in the Pennyroyal geological region, a karst-prone limestone plain dominated by sinkholes, sinking streams, springs, and caverns. The northeastern counties in the district (Nelson, Washington, Marion) lie in the Knobs region, an area of the Outer Bluegrass region that is characterized by isolated, steep sloping, and often cone-shaped hills.

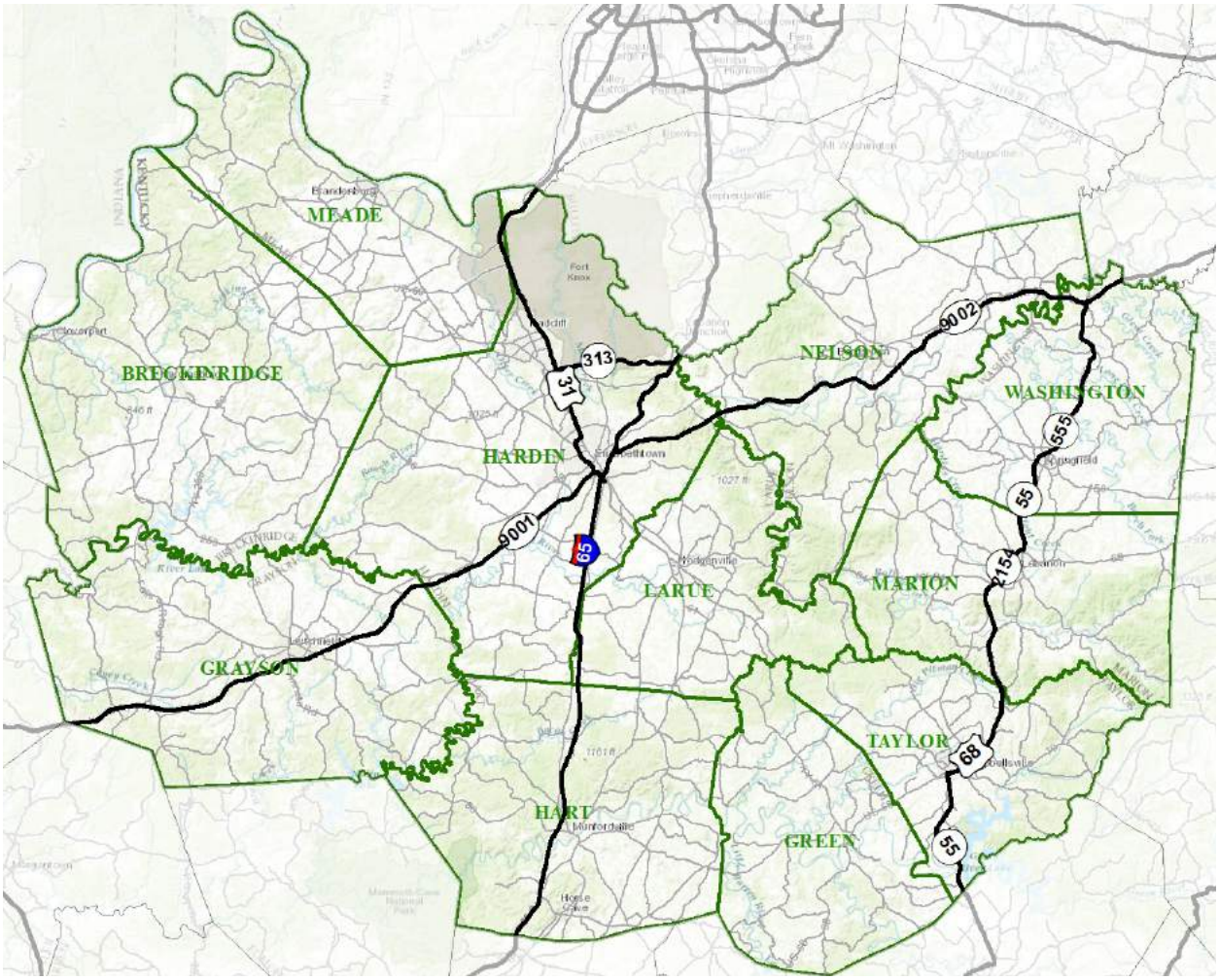


Figure 4-1. KYTC District 4 NHS

The NHS in District 4 is comprised of 439 miles of roadway (for divided highways, centerline miles are doubled in this total). Bisecting the district from north to south is Interstate 65, the most

heavily trafficked highway in the district and a major freight corridor of national significance. Parkways include WK-9001 (Western Kentucky Parkway) and BG-9002 (Bluegrass Parkway). US Highways include US-31W and US-68. Included in the District 4 NHS system are 32 bridges, 23 culvert locations, and 93 other structures. District 4 also has one Ohio River bridge on KY-79 in Brandenburg, though this bridge is not part of the NHS.

4.2.Hazards

NHS assets in District 4, including highway segments, bridges, culverts, and other structures (overpasses) were assessed against these four hazards using existing and available data. Table 4-1 summarizes the relationship between these NHS assets and the natural hazard indicators.

Table 4-1. Summary of District 4 NHS assets and natural hazard indicators

Asset Type	D4 Total	PGA ≥ 60 (Destructive)	PGA ≥ 30 and < 60 (Very Strong)	PGA ≥ 18 and < 30 (Strong)	In Flood Plain	Major Karst	Moderate Karst	High Landslide Susceptibility	Moderate Landslide Susceptibility
Total Road Miles	439	0	0	0	21	190	113	0	42
Interstate	118	0	0	0	7	96	4	0	0
Parkway	201	0	0	0	5	39	75	0	13
US Highway	74	0	0	0	7	49	10	0	23
KY Route	46	0	0	0	2	5	25	0	5
Local Road	0	0	0	0	0	0	0	0	0
Bridges	32	0	0	0	22	5	7	0	6
Culverts	23	0	0	0	14	8	4	0	2
Structures	93	0	0	0	3	45	17	0	6

4.2.1. Earthquake

District 4 lies outside New Madrid Seismic Zone, which is centered on the Mississippi-River, and the Wabash Valley Seismic Zone, centered on the Wabash River. Because of this, the area is unlikely to suffer significant impacts from an earthquake originating from either zone. Figure 4-2 depicts where District 4 is located relative to USGS defined PGA zones. District 4 lies within PGA zones ranging from 6 to 14. A PGA rating of 9 to 18 roughly equates to "Strong" on the Modified Mercalli-Scale, and is described as "Trees sway; suspended objects swing; objects fall off shelves." A PGA rating of 4 to 9 roughly equates to "Slightly Strong" on the Modified Mercalli-Scale, and is described as "Sleepers awake; church bells ring." Most of the District 4 NHS assets are in the "Strong" PGA Zones of 9 to 18, including I-65, the Western Kentucky Parkway, and US-31W. NHS assets in the District's eastern counties are in the "Slightly Strong" PGA Zones of 4 to 9, which are the lowest PGA zones in Kentucky.

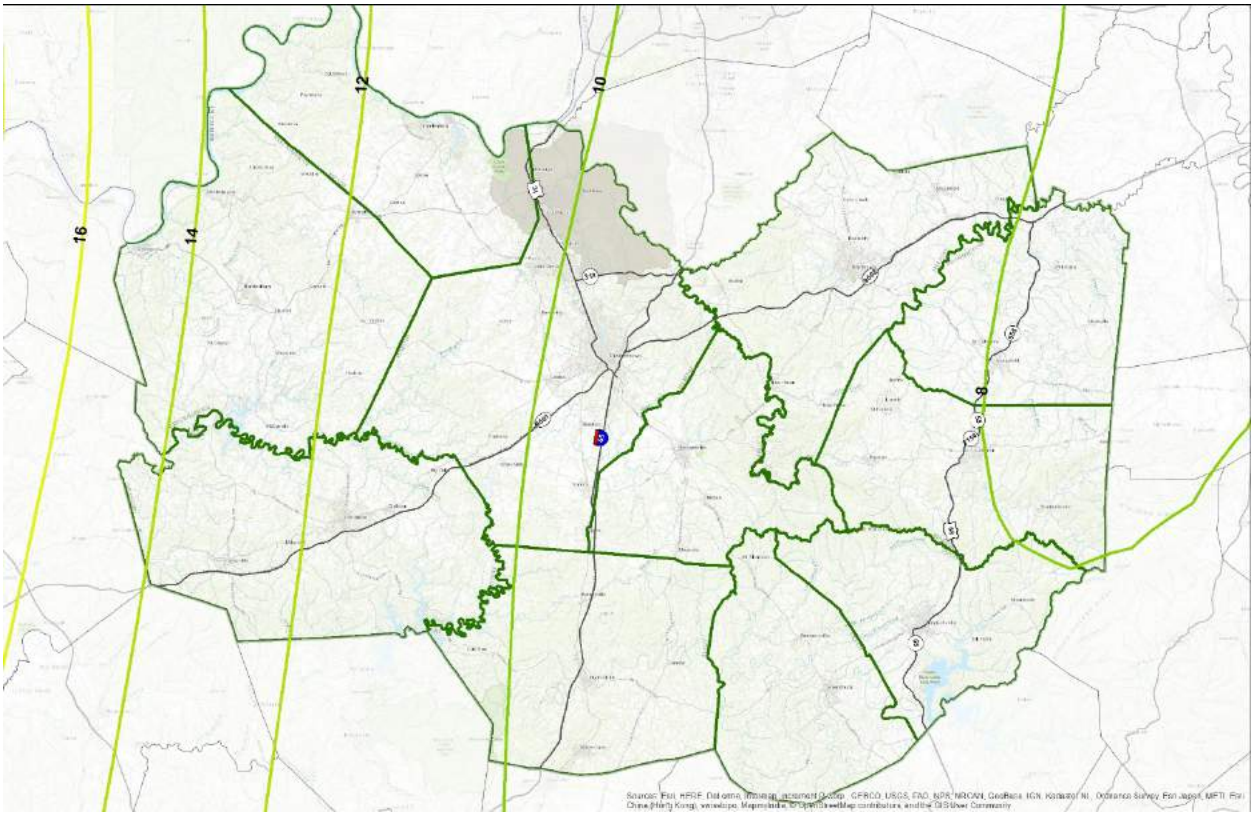


Figure 4-2. USGS PGA zones in KYTC District 4

4.2.2. Flood

District 4 is drained by several different river systems, all of which flow north and westward toward the Ohio River, including the Green River, Nolin River, Rough River and the Rolling Fork. In all, District 4 has 21 miles of NHS roadway located in the 100-year floodplain. Other NHS assets located in the 100-year floodplain are 22 bridges, 14 culverts, and 3 other structures.

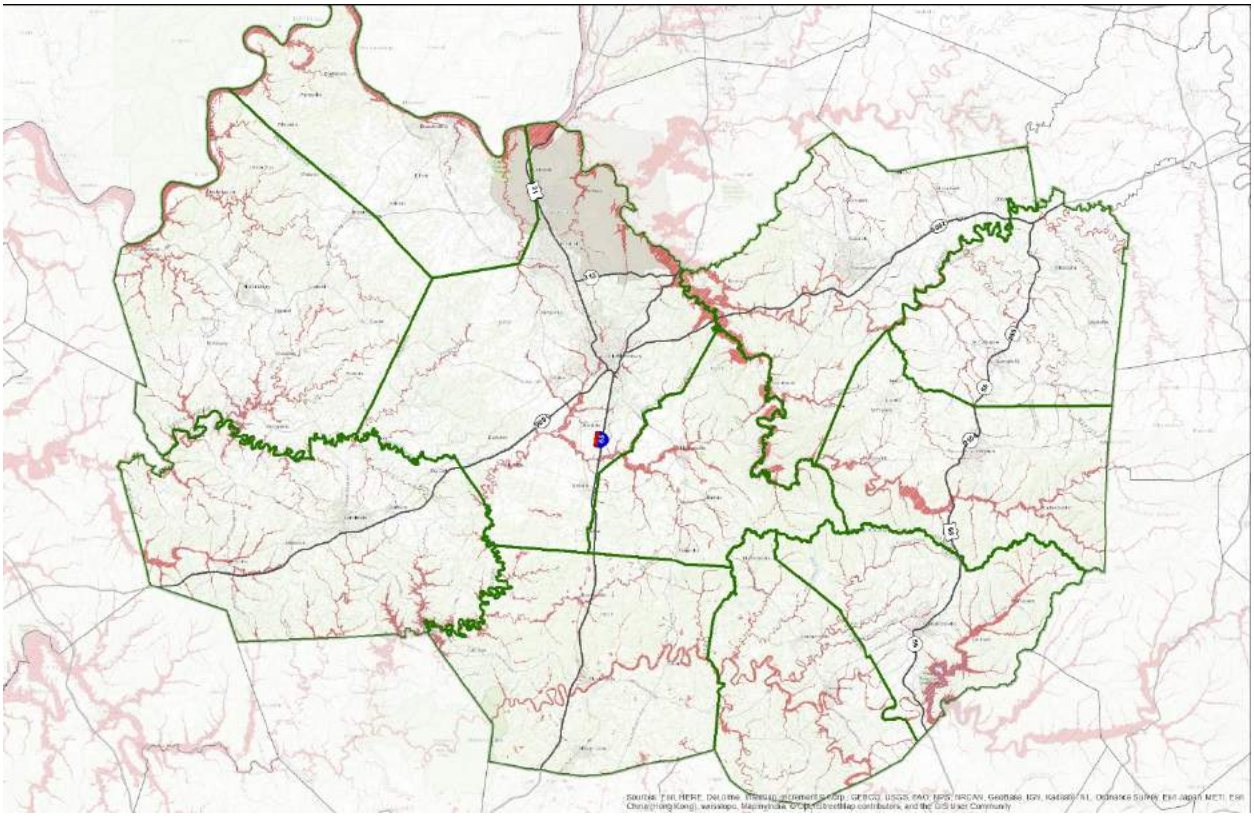


Figure 4-3. KYTC District 4; location of 100-year floodplain

Compared to the rest of the state, counties in District 4 have average or above average susceptibility to extreme rainfall events (greater than 3" of rain in a single calendar day). In the western part of the District, Grayson and Breckinridge Counties experienced extreme rainfall events on average every 2 to 3 years from 1981 to 2015, while the rest of District's counties experienced such events on average every 3 to 5 years. Extreme rainfall events of this magnitude often result in flash flooding. Fortunately, because the topography of District 3 is relatively flat, the impacts from such flash flooding have not been as damaging as they would have been with more rugged topography.

4.2.3. Landslide

Overall, landslide is a not a major hazard in District 4. However, some areas in the northeastern part of the district are somewhat susceptible to landslide, specifically where the Pennyroyal geological region transitions to the Knobs of the Outer Bluegrass region. Similarly, landslide susceptibility increases towards the western part of the district where the Pennyroyal region transitions to the Western Kentucky Coalfield region. As Figure 4-4 depicts, KGS-documented landsides in the district are largely clustered into these two areas. In these two clusters, six documented landslides occurred along the Western Kentucky Parkway in Grayson County and five have occurred along the Bluegrass Parkway in Nelson County.

There are no District 4 NHS assets located in areas identified by USGS as high landslide susceptibility. However, there NHS assets located in moderate landslide susceptibility areas that include 42 miles of roadway, 6 bridges, 2 culverts, and 6 other structures.

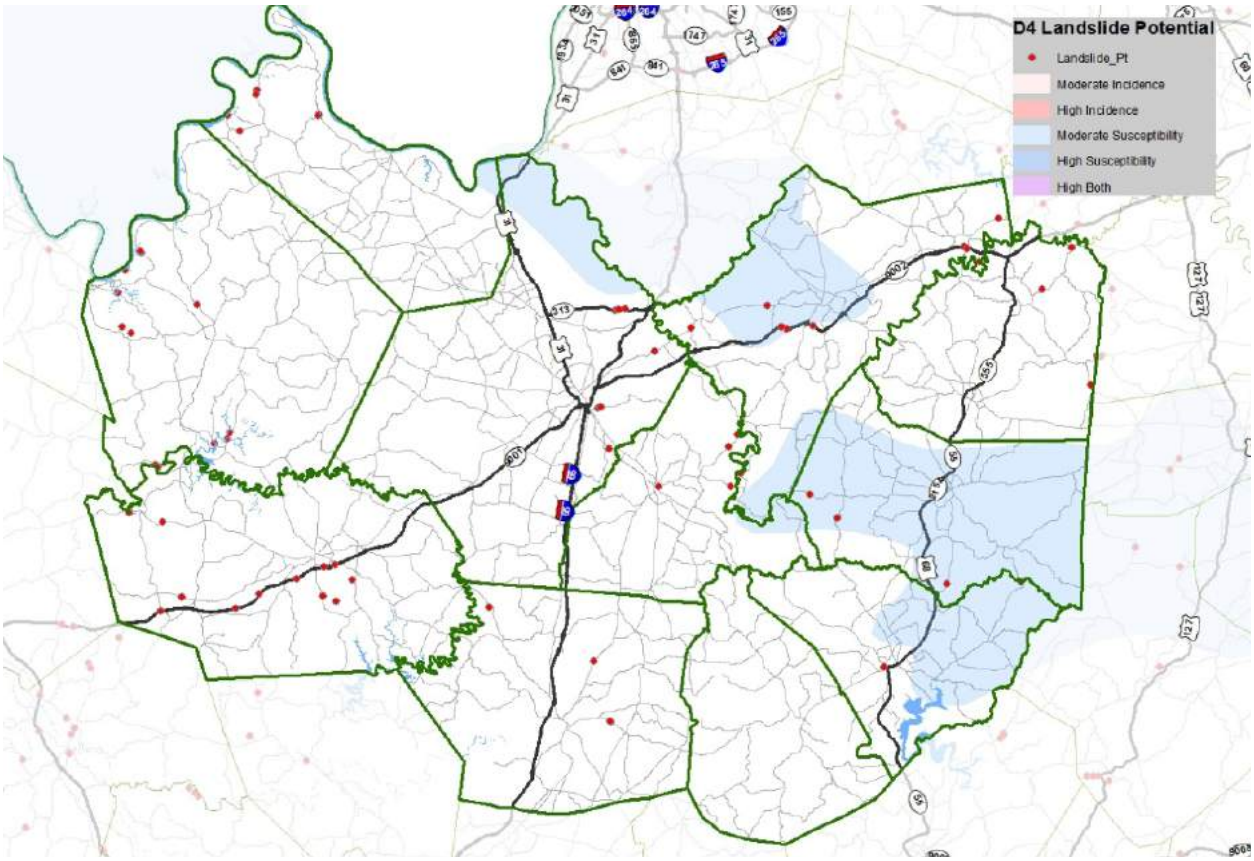


Figure 4-4. KYTC District 4 documented landslides and landslide susceptibility

Within the KGS landslide inventory database, landslides have been documented at the following locations along the NHS:

- Multiple slides along WK 9001 westbound at MP 101.3, MP 105, MP 107.8, and MP 108.8; Grayson County.
- Landslide below roadway WK 9001 MP 92; Grayson County.
- Landslide KY 313 at MP 002-004 and MP 003-004; Hardin County.
- Embankment failure on BG 9002 at MP 21 EB; Nelson County.
- Landslide BG 9002 at MP 18; Nelson County.
- Embankment failure BG 9002 at MP 37.2; Nelson County.
- Landslide corrections BG 9002 at MP 36.7 WB, MP 37.2 WB, and MP 38.3 EB; Nelson County.

4.2.4. Karst

Sinkholes are a major hazard in District 4, particularly in Hart, Green, LaRue, Hardin, and Meade Counties. I-65, the most critical NHS asset in the district, runs directly through an area of major karst formation and where sinkholes commonly occur (Figure 4-5). Other NHS assets in karst-prone areas included the Western Kentucky Parkway, KY-313 and US-31W in Hardin and Meade Counties.

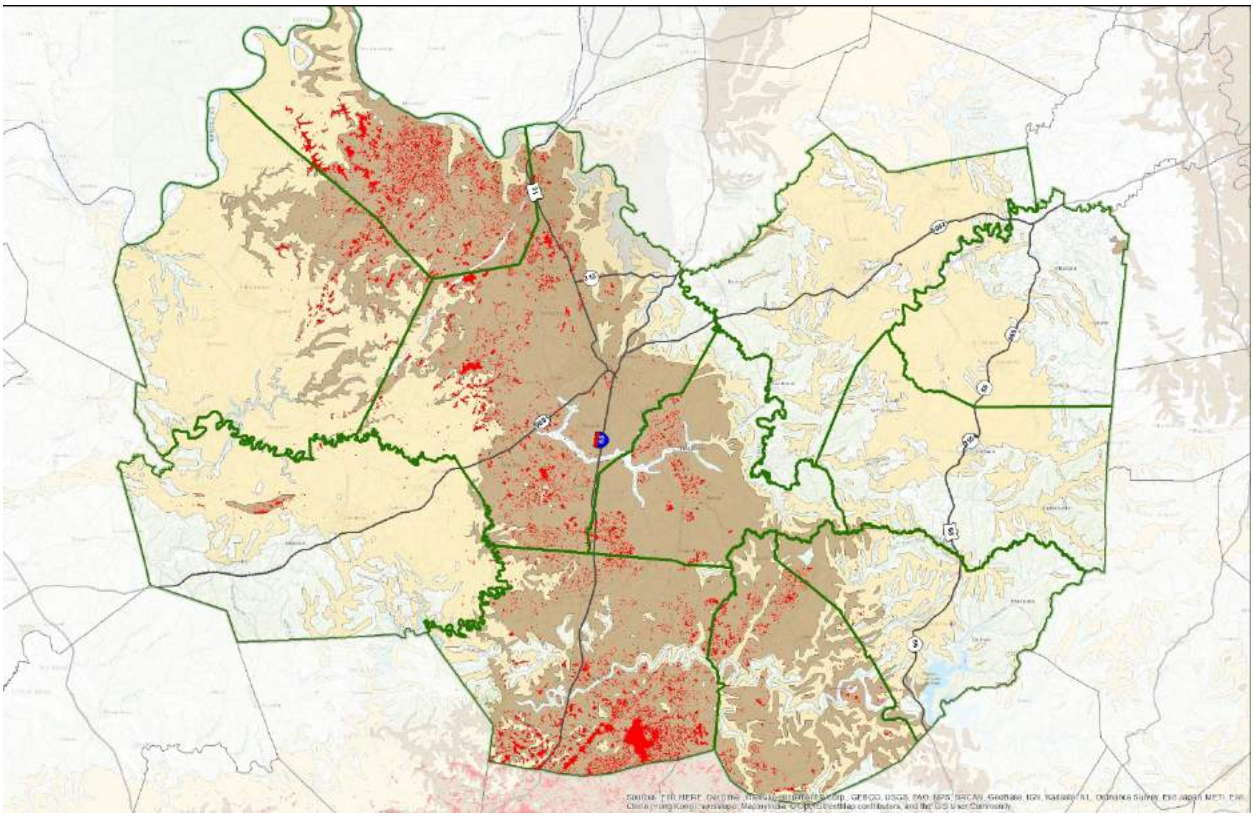


Figure 4-5. Karst potential and sinkholes in KYTC District 4

District 4 has 190 miles of NHS roadway located in areas of major karst potential, 96 of which are interstate and 39 of which are parkway. Other NHS assets that are located in high karst potential area include 5 bridges, 8 culverts, and 45 structures. Additionally, numerous sinkholes located along I-65, particularly south of Elizabethtown and most heavily clustered in the southern half of Hart County, have been identified by KGS.

4.2.5. Other Meteorological Hazards

- Snow/Ice: Most areas of District 4 average between 12" to 14" of annual snowfall, while the southern parts of the district average 10" to 12". These averages are in line with those in most of the central and northern parts of the state.
- Freeze/thaw: District 4 counties average between 82 and 90 annual freeze/thaw days. This is similar to the overall statewide average of 84 annual freeze/thaw days.
- Extreme heat: District 4 counties average between 3 and 6 days annually where the temperature exceeds 95 degrees Fahrenheit. Grayson County is the highest at over 6, while Taylor County is the lowest at 3.
- Drought/wildfire: Within the state, wildfire outbreaks are most common in southeastern Kentucky. From 2002-2015, USGS documented six wildfire events in District 4, all of which were minor. Of these, only one was near an NHS asset: in 2009 a minor wildfire was reported near Exit 81 along I-65 in Nelson County.
- Tornado: Of the KYTC districts, District 4 is the third most vulnerable to tornadoes. From 1950 to 2015, District 4 experienced 74 tornadoes overall, and 11 F3 to F5 tornadoes. Both of these totals are third highest among KYTC districts. In 1974, an F5 tornado ripped

through Breckinridge and Meade Counties, killing 31 people and injuring 270 others. It was one of only two F5 tornadoes ever documented in Kentucky.

4.3.Workshop

The research team conducted a facilitated workshop in District 4 in October 2016. Eleven KYTC personnel attended the workshop. During the workshop, data was collected from participants through a series of facilitated events, including: 1) two keypad exercises where participants were asked to score the criticality of the roadway and the potential impacts of an extreme weather and/or natural hazard event, 2) a mapping exercise with a focused conversation that contextualized flooding events in the District, and 3) a consensus workshop where participants identified and discussed challenges to performing transportation system maintenance.

4.3.1. Polling Results

The District 4 NHS was divided into 20 segments based upon road designation and county location. Workshop participants were provided with keypads and asked to evaluate each of the NHS segments for criticality and potential impacts from extreme weather and natural hazards. An overall vulnerability score for each segment was computed by multiplying together the criticality and impacts ratings. The vulnerability score, then, provides a metric for identifying highway segments that are both the most important and could potentially suffer the most damage from natural hazards. Table 4-2 displays the results of the workshop keypad assessments. The final column ranks each segment by the vulnerability score.

Table 4-2. District 4 workshop polling results showing criticality, impacts, and vulnerability

Segment ID	County	Segment Description	Criticality	Impacts	Vulnerability	Rank
1	Grayson	Western KY Parkway: Grayson County	6.8	5.3	36.0	8
2	Hardin	US 31W: West Point	6.3	5.4	34.0	9
3	Hardin	US 31W: Fort Knox	7.1	4.3	30.5	11
4	Hardin	US 31W: Radcliff	6.4	3.7	23.7	17
5	Hardin	US 31W: Hardin Cty from US 31WB to KY 313	5.8	3.8	22.0	19
6	Hardin	US 31WB: Elizabethtown	5.9	3.6	21.2	20
7	Hardin	KY 313: From I-65 to US 31W	6.1	4.0	24.4	15
8	Hardin	I-65: Hardin County north of WK 9001	8.6	6.9	59.3	4
9	Hardin	Western KY Parkway: Hardin County	6.7	5.4	36.2	7
10	Hardin	Bluegrass Parkway: Hardin County	7.1	5.1	36.2	6
11	Hardin	I-65: Hardin County south of WK 9001	8.6	7.0	60.2	2
12	Larue	I-65: Larue County	8.6	7.1	61.1	1
13	Hart	I-65: Hart County	8.5	7.0	59.5	3
14	Nelson	Bluegrass Parkway: Nelson County	7.0	5.4	37.8	5
15	Washington	Bluegrass Parkway: Washington County	6.8	5.0	34.0	10
16	Washington	KY 55/KY 555: Washington County	6.1	4.5	27.5	12
17	Marion	KY 55/KY 2154: Marion County	5.8	3.9	22.6	18
18	Marion	US 68: Marion County south of KY 2154	5.8	4.3	24.9	14
19	Taylor	US 68: Taylor County north of KY 55	5.8	4.1	23.8	16
20	Taylor	KY 55: Taylor County	5.7	4.7	26.8	13

4.3.2. Map Exercise

Workshop participants were asked to review and mark up eight detailed maps of the NHS in District 4. The maps included NHS roadway segments and the associated bridges, culverts, and other structures; other state highways; streams, rivers, and other bodies of water; and the 100-year floodplain. Participants were asked to mark the maps and provide as much detail as possible for areas along the NHS that have 1) flooded in the past and 2) have been close to flooding in the past. Table 4-3 displays the results of this exercise.

Table 4-3. District 4 NHS segments and flood

District	County	MP	Route	Hazard	Intersecting feature
4	Hardin	31.8	US-31W	Has flooded	None
4	Hardin	4.444	KY-313	Has flooded	None
4	Hardin	83.153	I-65	Has flooded	None
4	Marion	5.94	US-68	Has flooded	None

4.3.3. Workshop discussion

Sinkholes were identified during participant discussion as the greatest natural hazard for NHS assets in District 4, followed closely by flooding. Earthquakes and landslides were not considered by workshop participants to be significant hazards. However, several participants did mark areas on their maps where landslides had occurred in the past. In Grayson County, one participant stated that KY 259, south of Litchfield, has experienced landslides due to its proximity to Taylor Fork Creek. In Breckenridge County, northwest of Hardinsburg, a section of US 60 was marked as an area where a landslide had occurred in the past. In Meade County, on KY 228, North of Battletown, the roadway was identified as a place where a landslide had occurred in the past.

4.3.4. Maintenance facilities flooding

District 4 officials reported no problems with flooding at any KYTC maintenance facilities.

4.3.5. Roadways outside of the NHS that flood

Participants marked several other areas across District 4 that were not part of the NHS, but were susceptible to flooding. One area that multiple participants marked as having flooded in the past was in Elizabethtown along Dixie Highway (US 31W). However, the city of Elizabethtown is in the process of conducting some remediation work and participants were hopeful that the short duration floods would be alleviated.

4.3.6. Consensus workshop

For the consensus workshop, participants were asked to individually brainstorm about the following question; “What are the Greatest Challenges to Performing Maintenance in District 4?” As in District 3, participants were asked to work in small groups and then with the entire group. Table 4-4 provides the participants answers to the consensus workshop question.

Table 4-4. Results of District 4 consensus workshop

Identified Challenges to Conducting Maintenance Operations in District 4			
Dealing with the Public	**Need of Resources**	**Need More Experienced Manpower**	**Utilities are in the Way**
Ample Space to Work	Money, Money, Money	Staff Experience	Proximity of Utilities
Debris Disposal Issues	The Budget!	Lack of Experience	Utilities
Property Owner's Agreement	Lack of Staffing		Utility Coordination Issues
	Lack of Manpower		
	Lack of Funding		
	Lack of Equipment		

4.4.Results

4.4.1. Identification of most at vulnerable assets

Table 4-5 lists District 4 NHS assets with a vulnerability score of 3.5 or greater for any of the four major hazards in this analysis (a full list of District 4 NHS assets and vulnerability scores is in Appendix 2). Flood and sinkhole are the two hazards that cause the greatest vulnerabilities in District 4. I-65 in Hardin County is scored as having the greatest vulnerability to flooding, while I-65 in Hart County and Larue County is scored as having the greatest vulnerability to sinkholes. The results of this analysis mirror those from the keypad scoring at the District 4 workshop, where segments of I-65 in Hardin County, Hart County, and Larue County were also scored as having the greatest vulnerability.

Table 4-5. District 4 NHS assets with vulnerability score 3.5 or greater

District	County	Route	Vulnerability Score	Hazard
4	Hardin	US 31W	**3.63**	Flood
4	Hardin	I-65	**3.87**	Flood
4	Hardin	I-65	**3.67**	Sinkhole
4	Hardin	US 31W	**3.67**	Sinkhole
4	Hardin	WK 9001	**3.72**	Sinkhole
4	Hardin	I-65	**3.89**	Sinkhole
4	Hart	I-65	**4.00**	Sinkhole

4	Larue	I-65	**4.00**	Sinkhole

4.4.2. Worst case scenario

Like District 3, the worst case plausible scenario in District 4 would be for a sinkhole to form under I-65 and damage or destroy the roadbed. In central and southern Kentucky, I-65 runs through an area of high karst potential. The landscape there is dotted with thousands of sinkholes, springs, sinking streams, and caves. Sinkholes have caused problems with roadways in this district in the recent past, notably along the Western Kentucky Parkway in Hardin County. It is possible that a new sinkhole could form and negatively impact I-65, the most critical NHS asset in the district.

5. KYTC District 5

5.1.District Overview

KYTC District 5 is in the north-central part of Kentucky, and includes Bullitt, Franklin, Henry, Jefferson, Oldham, Shelby, Spencer, and Trimble Counties. The District 5 office is located in Louisville, Kentucky's largest city with a metropolitan area population in Kentucky of 765,352 in 2016[19]. All of the District 5 counties except for Franklin are included as part of Louisville's metropolitan organization, KIPDA (Kentuckiana Regional Planning and Development Agency). The Ohio River forms the northeastern boundary of District 5. Other major rivers in the district include the Kentucky River, Salt River, and Rolling Fork. The majority of the District 5 area is in the Outer Bluegrass geological region, which is characterized as a rolling plateau that is more rugged near the edges. The southern areas of the district are in the Knobs region, an area of the Outer Bluegrass region that is characterized by isolated, steep sloping, and often cone-shaped hills. The city of Louisville was founded at the Falls of the Ohio, the only natural break along the entire extent of the river.

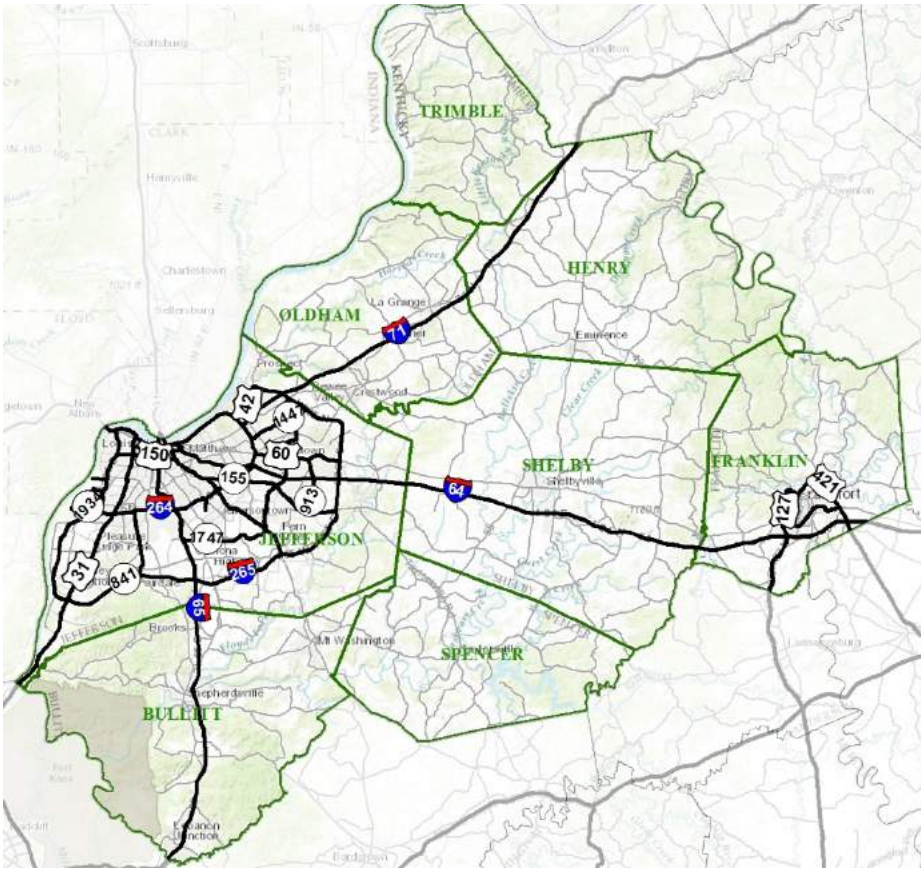


Figure 5-1. KYTC District 5 NHS

The District 5 NHS is comprised of 772 miles of roadway, including 506 miles of interstate, 116 miles of US highway, 141 miles of KY highway, and 8 miles of local roads (for divided highways, centerline miles are doubled in these totals). Included in this is I-65, the most heavily trafficked

[19] U.S. Census Bureau, Population Division, "SubCounty Population Estimates: April 1, 2010 to July 1, 2016."

highway in the district and a major freight corridor of national significance, as well as I-64, I-71, I-264, and I-265. US Highways that are a part of the NHS in the district include US-31, US31-E, US-31W, US-42, US-60, US-127, US-150, and US-421. Included in the District 5 NHS system are 64 bridges, 43 culvert locations, and 333 other structures. District 5 NHS also includes several major bridges over the Ohio River, including the I-64 Sherman Minton Bridge, US-31 Clark Memorial Bridge, and I-65 John F. Kennedy Memorial Bridge. In 2016, the construction of two new Ohio River bridges was completed: the I-65 Abraham Lincoln Bridge and I-265 Lewis and Clark Bridge.

5.2.Hazards

District 5 NHS assets, including highway segments, bridges, culverts, and other structures were assessed against the four primary hazards identified for this project: earthquake, flood, sinkhole, and landslide. Table 5-1 summarizes the relationship between these NHS assets and selected natural hazard indicators.

Table 5-1. Summary of District 5 NHS assets and natural hazard indicators

Asset Type	D5 Total	PGA ≥ 60 (Destructive)	PGA ≥ 30 and < 60 (Very Strong)	PGA ≥ 18 and < 30 (Strong)	In Flood Plain	Major Karst	Moderate Karst	High Landslide Susceptibility	Moderate Landslide Susceptibility
Total Road Miles	772	0	0	0	14	311	142	0	31
Interstate	506	0	0	0	6	190	132	0	29
Parkway	0	0	0	0	0	0	0	0	0
US Highway	116	0	0	0	4	51	2	0	2
KY Route	141	0	0	0	3	69	8	0	0
Local Road	8	0	0	0	0	1	0	0	0
Bridges	64	0	0	0	20	20	11	0	4
Culverts	43	0	0	0	13	17	15	0	3
Structures	333	0	0	0	4	121	50	0	11

5.2.1. Earthquake

Earthquake is not a significant hazard for District 5. Figure 5-2 shows where District 5 lies relative to USGS defined PGA zones. District 5 lies in PGA zones ranging from 6 to 10. Franklin County and eastern sections of Shelby and Henry Counties lie in PGA Zone 6, which is the lowest PGA zone found in Kentucky. Nearly all the remainder of District 5 is located in PGA Zone 8. PGA Zones 6-8 compare on the Modified Mercalli-Scale to "Slightly Strong", which is described as "Sleepers awake; church bells ring." Seismic activity at this level would not be expected to negatively impact NHS assets in District 5. The far western part of Jefferson County lies in PGA Zone 10, which compares to "Strong" on the Modified Mercalli-Scale, and is described as "Trees sway; suspended objects swing; objects fall off shelves." District 5 has 43 miles of NHS roadway located in PGA Zone 10, including parts of US-31W, KY-841, and KY-1934. Other NHS included in this area are 5 bridges, 2 culverts, and 9 other structures.

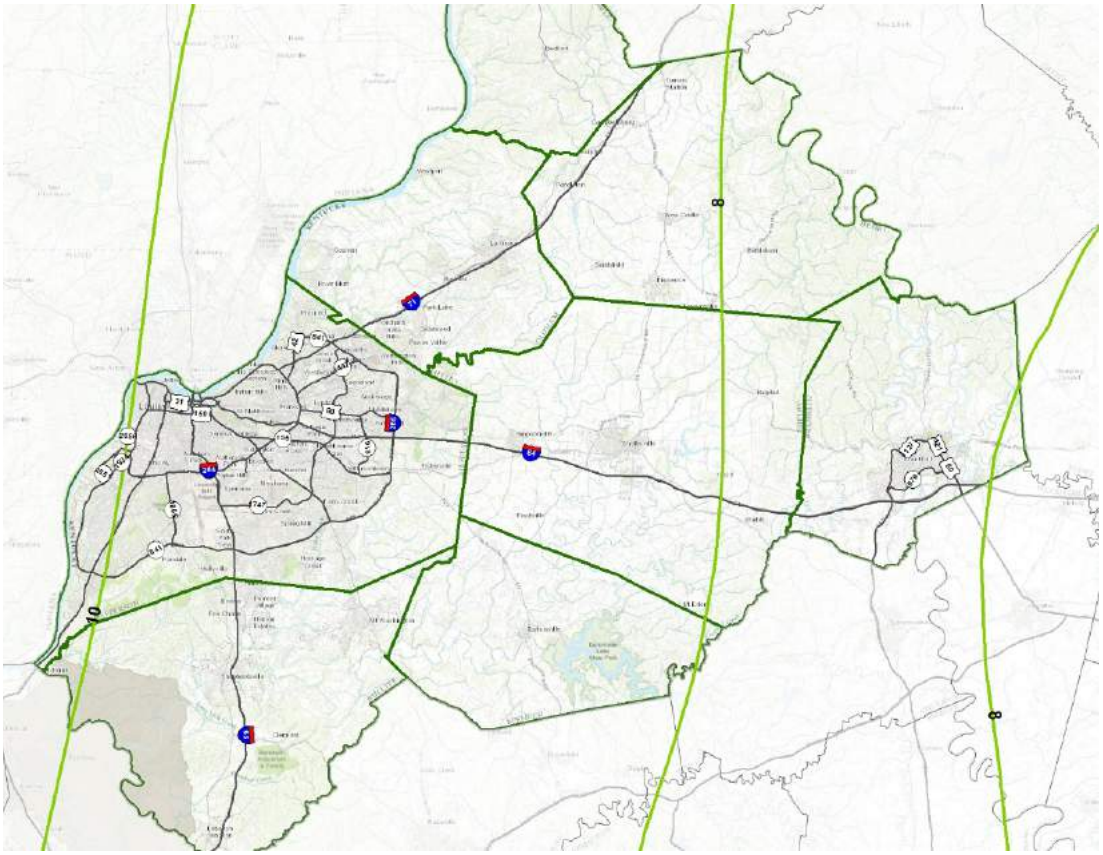


Figure 5-2. USGS PGA Zones in KYTC District 5

5.2.2. Flood

District 5 is drained by several different river systems, all of which eventually flow north and westward to the Ohio River. Though District 5 is vulnerable to both river flooding and flash flooding, the NHS in this district is fairly well built-up and not so vulnerable. The city of Louisville is vulnerable to Ohio River flooding, while the city of Frankfort is vulnerable to Kentucky River flooding. Within Kentucky, District 5 has a slightly higher than average frequency of extreme rainfall events (greater than 3" of rain in a single calendar day) compared to the state as a whole.

District 5 experienced such extreme rainfall events on average every 3 to 4 years from 1981 to 2015, compared to the state average of every 4 years.

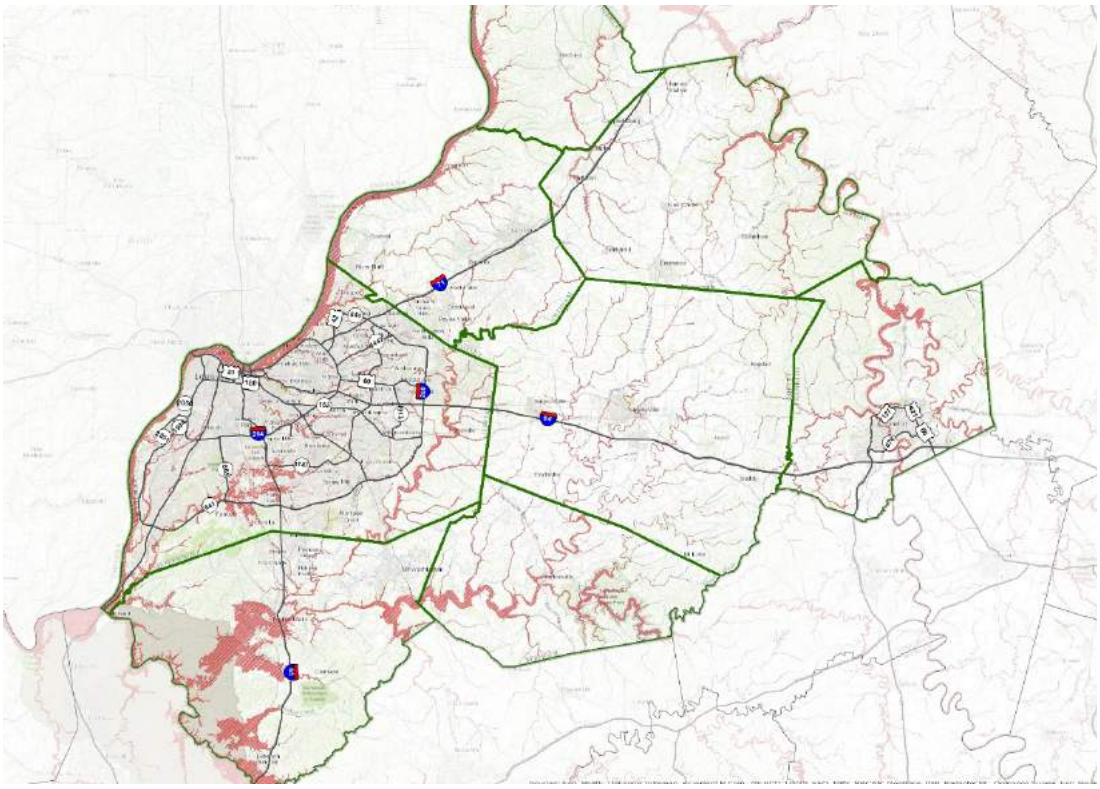


Figure 5-3. KYTC District 5; location of 100-year floodplain

Overall, there are 14 miles of NHS roadway in the district located in the 100-year floodplain. Other NHS assets located in the 100-year floodplain include 20 bridges, 13 culverts, and 4 other structures. District 5 does not have any NHS segments that are particularly vulnerable to flood, though several have been reported as flooding in the past. These include I-64 in Jefferson County near Beargrass Creek, and I-64 in Shelby County near Jeptha Creek.

5.2.3. Landslide

The majority of District 5 is relatively flat and is not particularly vulnerable to landslides. Figure 5-4 depicts landslide incidence and susceptibility in the district. Landslides in the district are generally scattered with the highest cluster of incidences occurring in the Knobs region of Bullitt County. KGS has also documented landslides in Franklin County, particularly along the Kentucky River valley. NHS segments in District 5 that have been impacted by landslides include KY 841 in Jefferson County west of I-65, I-65 in Bullitt County, I-64 in Shelby and Franklin Counties, and KY 676 in Franklin County.

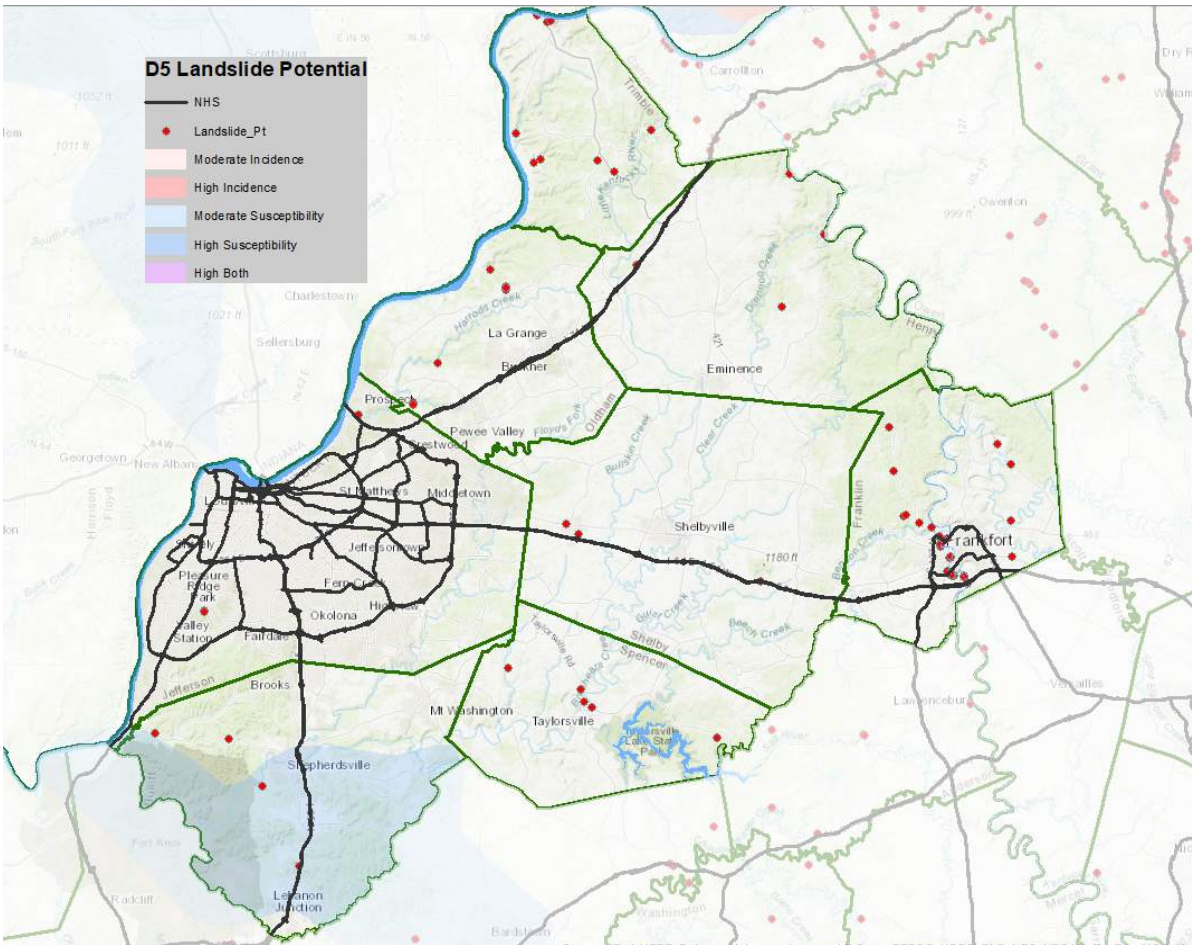


Figure 5-4. KYTC District 5 documented landslides and landslide susceptibility

Within the KGS landslide inventory database, landslides have been documented at the following locations along the NHS:

- Landslide I-265 between MP 10 and MP 11; Jefferson County.
- Landslide I-265 between MP 22 and MP 24; Jefferson County.
- Approach fill failure for I-71 Bridge over KY 1606 between I-71 MP 29 and MP 30; Henry County.
- I-64 embankment slip MP 40.8; Shelby County.
- KY 1659 landslide below roadway, stream bottom MP 1.17; Franklin County.
- Embankment monitoring US 127 at MP 8.4; Franklin County.
- Mudslide US 420 above roadway, road closure; Franklin County.
- Mudslide I-65 between MP 108.4 and 108.8; Bullitt County.

5.2.4. Karst

Certain parts of District 5 located in eastern Jefferson and Bullitt County, Oldham County, and Franklin County are vulnerable to sinkholes. In all, 311 miles of NHS roadway are located in areas of major karst potential. Of these 311 miles, 190 are interstate, 51 miles are US highway, 69 are

state routes, and 1 of which is a city/county road. NHS structures located in areas of high karst potential include 20 bridges, 17 culverts, and 121 other structures.

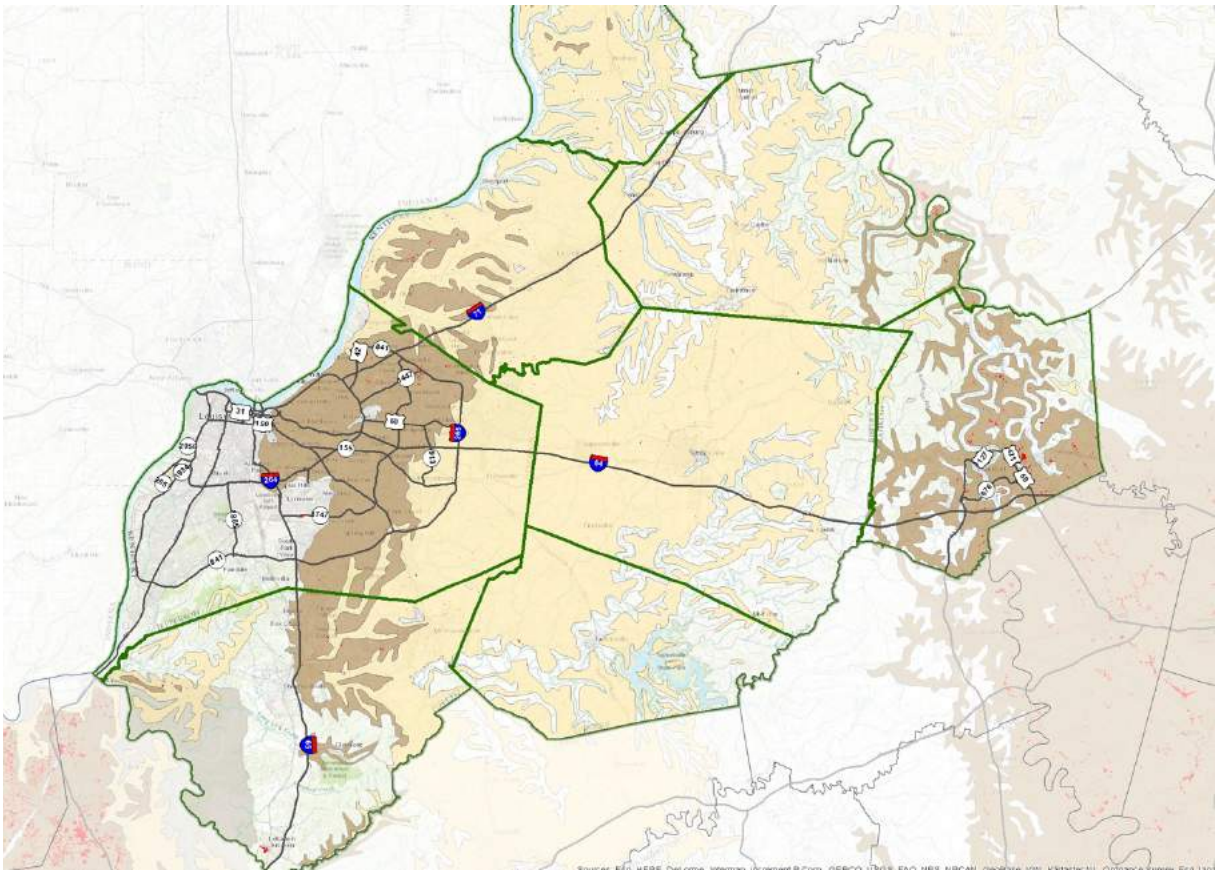


Figure 5-5. Karst potential and sinkholes in KYTC District 5

Other Meteorological Hazards

- Snow/Ice: District 5 averages between 10" to 16" of annual snowfall, with the eastern areas averaging closer to 10" and the northwestern areas averaging closer to 16".
- Freeze/thaw: District 5 has about average annual number of freeze/thaw days compared to the rest of the state. Counties in the district averaged 77-92 freeze/thaw days annually between 1981 and 2015, compared to the overall state average of 84. Jefferson County averages the fewest freeze/thaw days annually, which can likely be attributed to the heat island effect of the urbanized area.
- Extreme heat: District 5 also has about average annual number of extreme heat days compared to the rest of the state. Counties in District 5 averaged between 2 to 6 annual days between 1981 and 2015 where the maximum temperature exceeded 95 degrees Fahrenheit. Bullitt County had the highest annual average in the district at 5.8 days, while Trimble County had the lowest average at 2.3. The statewide average was just under 4.
- Drought/wildfire: Within the state, wildfire outbreaks are most common in southeastern Kentucky. From 2002-2015, USGS documented five wildfire events in District 5, all of which were minor in scale: three near the Fort Knox reserved lands in Bullitt County, one north of I-64 near the Shelby/Franklin county line, and one south of I-71 in Henry County.

- Tornado: Compared to the other 12 KYTC Districts in Kentucky, District 5 has average vulnerability to tornadoes. From 1951 to 2015, District 5 experienced the sixth most overall tornadoes (55) and the fifth most F3 to F5 tornadoes (10) in Kentucky.

5.3.Workshop

The research team conducted a facilitated workshop in District 5 in October 2017. Four KYTC personnel attended the workshop. During the workshop, data was collected from participants through a series of facilitated events, including: 1) two keypad exercises where participants were asked to score the criticality of the roadway and the potential impacts of an extreme weather and/or natural hazard event, 2) a mapping exercise with a focused conversation that contextualized flooding events in the District, and 3) a consensus workshop where participants identified and discussed challenges to performing transportation system maintenance.

5.3.1. Polling Results

For workshop exercise purposes, the NHS in the district was divided into 37 functional segments. The majority of these segments are located in the urbanized area of Jefferson County. Some of these segments included multiple routes, particularly in the central business district of Louisville. Workshop participants were provided with keypads and asked to evaluate each of the NHS segments for criticality and potential impacts from extreme weather and natural hazards. An overall vulnerability score for each segment was computed by multiplying together the criticality and impacts ratings. The vulnerability score, then, provides a qualitative metric for identifying highway segments that are both the most important and could potentially suffer the most damage from natural hazards. Table 5-2 displays the results of the workshop keypad assessments. The final column ranks each segment by the combined score.

Table 5-2. KYTC District 5 workshop polling results showing criticality, impacts, and vulnerability

Segment ID	Segment Description	Criticality	Impacts	Combined	Rank
1	Sherman Minton Bridge, I-64 downtown	8.3	3.3	27.8	10
2	I-64 inside I-265	7.3	4.0	29.3	9
3	I-64 east of I-265	7.0	2.0	14.0	28
4	Kennedy Bridge, I-65	8.8	2.0	17.5	21
5	Lincoln Bridge, I-65	8.8	1.7	14.6	26
6	I-65 north of I-264	8.0	1.0	8.0	36
7	I-65 south of I-264	8.5	3.0	25.5	12
8	I-71	8.0	4.3	34.7	6
9	I-264 west of I-65	6.8	2.7	18.0	20
10	I-264 east of I-65	8.3	2.5	20.6	18
11	KY 841 west of I-65	6.0	7.7	46.0	1
12	I-265 From I-65 to I-71	8.5	2.7	22.7	16
13	Lewis & Clark Bridge, KY 841	7.0	2.0	14.0	28
14	Clark Memorial Bridge, US 31	6.7	2.3	15.6	23
15	Downtown (2nd, 3rd, S Brook, S Jefferson, S Liberty)	7.0	2.7	18.7	19
16	Roy Wilkins + Federal Bldg access	5.3	1.0	5.3	37
17	US 31W (W Main/W Market/Dixie Hwy)	7.0	3.7	25.7	11
18	US 31E (E Main/E Market/Bardstown Rd)	7.3	2.0	14.7	24
19	US 42 (Story/Mellwood/Brownsboro Rd)	6.3	3.7	23.2	15
20	US 150 (Broadway)	7.0	1.7	11.7	32
21	KY 1934/KY 2056/KY 2051 (river industrial access)	7.5	3.3	25.0	13
22	KY 1865 (New Cut Rd)	7.0	2.0	14.0	28
23	Grade Ln (UPS/Ford access)	7.3	5.0	36.7	4
24	Newburg/Bishop (industrial access)	7.0	2.3	16.3	22
25	KY 1747 (Fern Valley Rd/Hurstbourne Ln)	7.0	2.0	14.0	28
26	KY 155 (Taylorsville Rd)	6.7	1.5	10.0	33
27	US 60 (Frankfort Ave/Shelbyville Rd)	7.3	3.0	22.0	17

Segment ID	Segment Description	Criticality	Impacts	Combined	Rank
28	KY 1447 (Westport Rd)	6.3	1.3	8.4	35
29	KY 913 (Blankenbaker Parkway)	7.0	1.3	9.3	34
30	I-71 Oldham County	8.3	3.7	30.6	8
31	I-71 Henry and Trimble County	6.7	3.7	24.4	14
32	I-64 Shelby County	8.0	4.0	32.0	7
33	I-64 Franklin County	7.7	5.3	40.3	2
34	US 127 Franklin County	6.5	2.3	14.6	25
35	US 60 / KY 421 Franklin County	7.0	5.0	35.0	5
36	KY 676 Franklin County	6.3	2.3	14.1	27
37	I-65 Bullitt County	8.3	4.7	38.9	3

5.3.2. Map Exercise

Workshop participants were asked to review and mark-up eight detailed maps of the NHS in District 5. The maps included NHS roadway segments and the associated bridges, culverts, and other structures; other state highways; streams, rivers, and other bodies of water; and the 100-year floodplain. Participants were asked to mark the maps and provide as much detail as possible for areas along the NHS that have 1) flooded in the past and 2) have been close to flooding in the past. Table 5-3 displays the results of this exercise.

Table 5-3. District 5 NHS segments and flood

District	County	MP	Route	Hazard	Intersecting feature
5	Jefferson	8.25	I-64	Has flooded	Tunnels
5	Jefferson	7.5	I-64	Has flooded	Middle Fork Beargrass Creek

5.3.3. Workshop discussion

Overall, KYTC NHS assets in District 5 have lower vulnerability to natural hazards than other KYTC districts. Only one NHS segment was identified as having flooded in recent memory, that being I-64 in Jefferson County near Beargrass Creek. Current mitigation work by the Metropolitan Sewer District (MSD) in Louisville to address storm water overflow will likely decrease the number of flooding events at this location. The most recent Ohio River flood occurred in 1997 and temporarily closed I-64 and I-65; a disruption that was short-lived. In August of 2009 downtown Louisville was impacted by a flash flood as 3 to 6 inches of rain fell over the course of just a few hours. Much of downtown was submerged as the water could not drain quickly enough.

5.3.4. Roadways outside of the NHS that flood

In Trimble County, KY-754 floods fairly regularly. This causes problems as it is one of the major access roads to the Trimble County Generating Station. KY-2871 in Trimble County also floods frequently enough that officials often just leave out the water over roadway signs. In Franklin County, a 2001 flash flood overran US-421 north of Frankfort resulting in a fatality. Spencer County has several roads that flood along the Salt River and Brashears Creek, including KY-2885 and KY-1633. In Bullitt County, KY-480 at mile point 10 is reported to flood nearly every there is a hard rainfall. A 2015 Bullitt County flood was also reported to have washed out bridges on KY-1417 and KY-22.

5.3.5. Maintenance facilities flooding

No District 5 maintenance facilities were reported as having problems with flooding.

5.3.6. Consensus workshop

For the consensus workshop, participants were asked to individually brainstorm about the following question; “What are the Greatest Challenges to Performing Maintenance in District 5?” Participants were asked to work in small groups to discuss and clarify their ideas. Ideas were then presented and group with all the participants. Table 5-4 provides the participants answers to the consensus workshop question.

Table 5-4. Results of District 5 consensus workshop

Identified Challenges to Conducting Maintenance Operations in District 5					
Safety Vs Beautification -Priorities	**Limited Access -Certain Windows**	**Need More People**	**Money**	**Deteriorating Infrastructure**	**Expectation Level from Public**
	Daytime Traffic Access	Staffing			
	Dealing with Traffic	Warm Bodies			
		Reactive vs Proactive			
		Limited Staff Safety > Beautification			
		Number of People			

5.4.Results

5.4.1. Identification of most at vulnerable assets

Only one NHS asset in District 5 had a vulnerability score of 3.5 or greater. District 5 had the fewest assets of any KYTC District in the state scoring below the threshold. Other NHS assets that had the highest vulnerability score in the District included I-64 in downtown Louisville (3.46 vulnerability score to flood), I-65 in downtown Louisville (3.29 vulnerability score to flood), 2nd and 3rd Street in downtown Louisville (3.38 vulnerability score to flood), I-264 in western Jefferson County (3.46 vulnerability score to flood), US-42 in Jefferson County (3.37 vulnerability score to flood), I-64 in Shelby County (3.29 vulnerability score to flood), Gene Snyder Freeway west of I-65 (3.32 vulnerability score to landslide), I-64 in Franklin County (3.45 vulnerability score to landslide), and I-65 in Bullitt County (3.32 vulnerability score to landslide). These NHS assets were also among those scored highest for vulnerability by workshop participants. A full list of District 5 NHS assets and vulnerability scores can be found in Appendix 2.

Table 5-5. District 5 NHS assets with vulnerability score 3.5 or greater

District	County	Route	Vulnerability Score	Hazard
5	Jefferson	US-31W	**3.54**	Flood

5.4.2. Worst case scenario

A major catastrophic flood, breaching or overtopping the existing flood walls built to protect the greater metropolitan Louisville area, was identified as the worst case scenario for the district. The Louisville levee system was constructed after the 1937 flood that caused massive damage and destruction to the area. Louisville has not experienced higher flood elevations than what occurred during the 1937 Flood. However, with future climate models suggesting higher precipitation accumulations for the Ohio River Valley, an event exceeding the 1937 Flood elevations is certainly possible in the future.

6. District 6

6.1.KYTC District Overview

KYTC District 6 is the northernmost district in Kentucky and includes the counties of Boone, Bracken, Campbell, Carroll, Gallatin, Grant, Harrison, Kenton, Owen, Pendleton, and Robertson. Portions of Boone, Kenton, and Campbell Counties are highly urbanized as part of the greater Cincinnati metropolitan area. This area comprises the third largest population cluster in Kentucky, after Louisville and Lexington. The Ohio River forms the northern border of District 6. Other major rivers in the district include the Licking River and Kentucky Rivers which both flow northward into the Ohio River. The majority of District 6 is in the Outer Bluegrass geological region, characterized as a rolling plateau with rugged areas near the edges of the region. In the south-central part of the district, parts of Pendleton and Harrison Counties along South Fork Licking River are part of the Inner Bluegrass region, which is characterized by rolling hills, fertile soils, and karst topography.

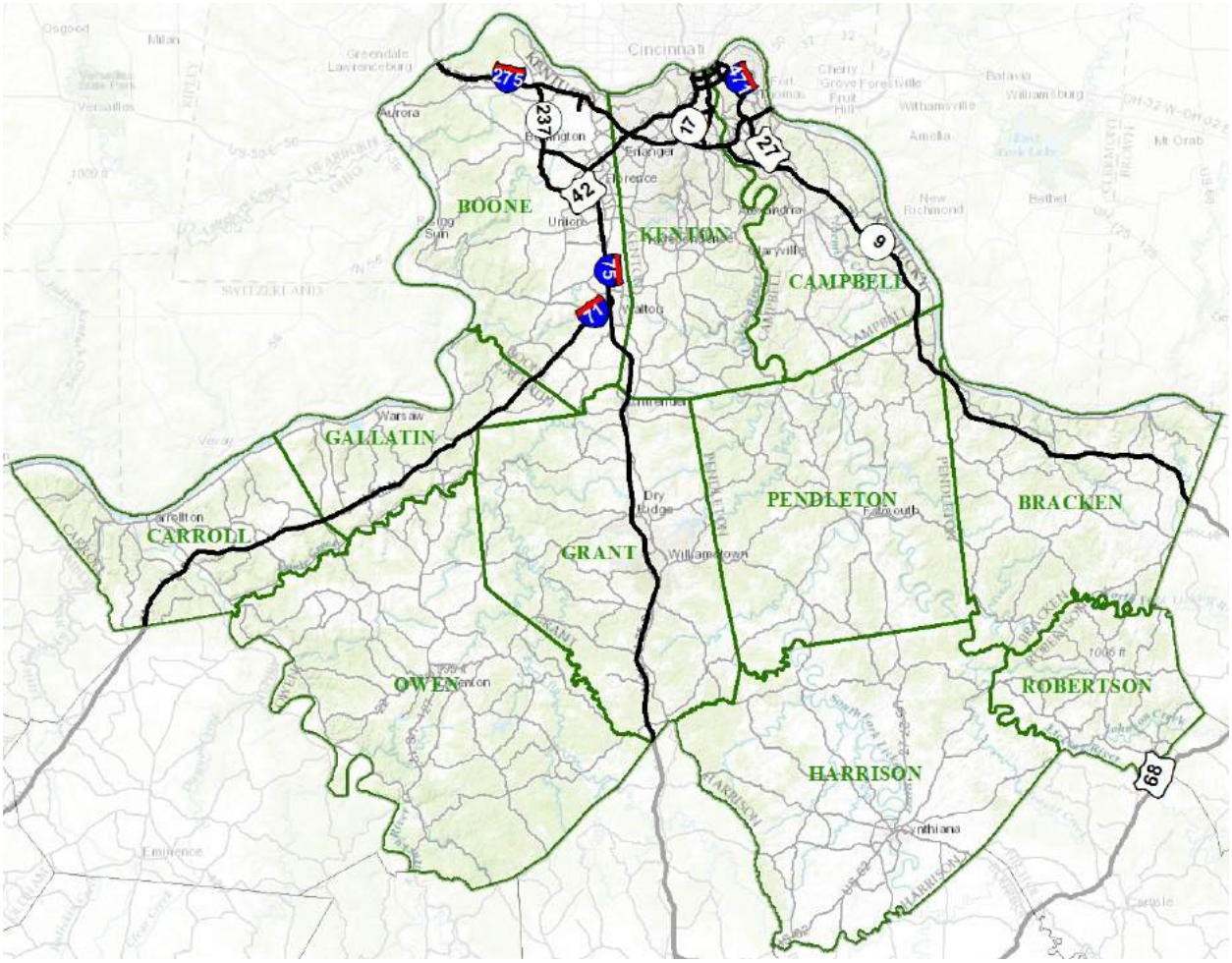


Figure 6-1. KYTC District 6 NHS

The District 6 NHS is comprised of 429 centerline miles of roadway (for divided highways, centerline miles are doubled in this total). District 6 NHS includes several major interstates, including I-71, I-75, I-275, and I-471. US Highways include US-27, a brief section of US-42, and

US-68. District 6 also includes the AA Highway (KY-9). Included in the District 6 NHS system are 29 bridges, 8 culvert locations, and 149 other structures. District 6 NHS also includes several major bridges over the Ohio River, including the I-275 Carroll C. Cropper Bridge, the I-71 Brent Spence Bridge, KY-17 John A. Roebling Bridge, US-27 Taylor Southgate Bridge, I-471 Daniel C. Beard Bridge, and I-275 Combs-Hehl Bridge. Ohio River bridges in the district that are not included in the NHS are the KY-1039 Bridge in Gallatin County and the US-42 C.W. Bailey Bridge in Kenton County.

6.2.Hazards

District 2 NHS assets, including highway segments, bridges, culverts, and other structures were assessed against the four primary hazards identified for this project: earthquake, flood, sinkhole, and landslide. Table 6-1 summarizes the relationship between these NHS assets and selected natural hazard indicators.

Table 6-1. Summary of District 6 NHS assets and natural hazard indicators

Asset Type	D6 Total	PGA ≥ 60 (Destructive)	PGA ≥ 30 and < 60 (Very Strong)	PGA ≥ 18 and < 30 (Strong)	In Flood Plain	Major Karst	Moderate Karst	High Landslide Susceptibility	Moderate Landslide Susceptibility
Total Road Miles	429	0	0	0	1	0	223	130	0
Interstate	306	0	0	0	1	0	173	75	0
Parkway	0	0	0	0	0	0	0	0	0
US Highway	16	0	0	0	0	0	11	8	0
KY Route	107	0	0	0	0	0	39	47	0
Local Road	0	0	0	0	0	0	0	0	0
Bridges	29	0	0	0	8	0	0	15	0
Culverts	8	0	0	0	3	0	3	2	0
Structures	149	0	0	0	3	1	67	65	0

6.2.1. Earthquake

Of all KYTC districts, District 6 is the least vulnerable to earthquakes. Figure 6-2 shows where District 6 lies relative to USGS defined PGA zones. The majority of District 6 lies in PGA Zone 6, which is the lowest found in Kentucky. Parts of Carrol, Pendleton, Grant, Bracken, Harrison, and Robertson are in PGA Zone 8. Both of these zones align on the Modified Mercalli-Scale to "Slightly Strong", which is described as "Sleepers awake; church bells ring." Seismic activity at this level would not be expected to negatively impact NHS assets in District 6.

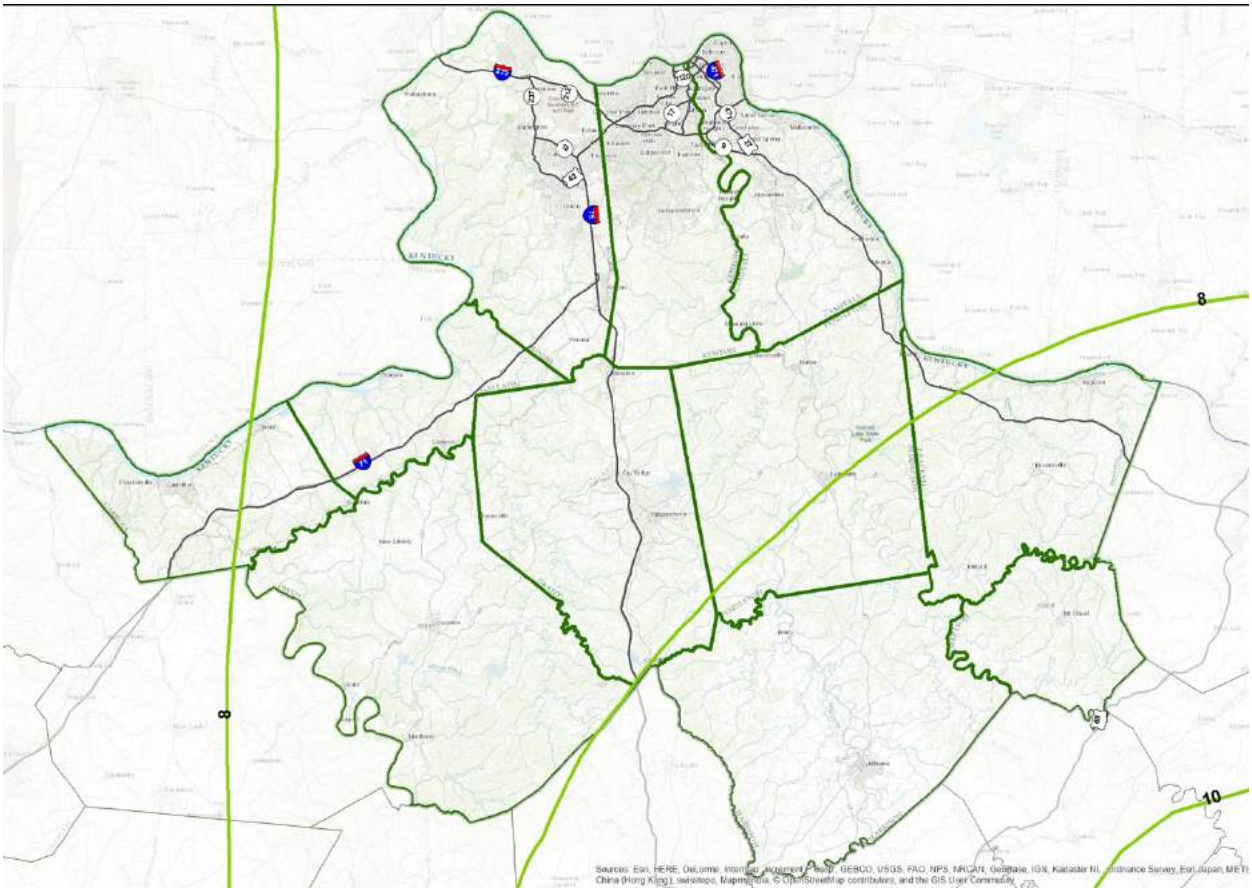


Figure 6-2. USGS PGA Zones in KYTC District 6

6.2.2. Flood

The Ohio, Licking, and Kentucky Rivers are all located in KYTC District 6. Although these rivers all have large floodplains in the District, there is only one mile of NHS roadway located in the 100-year floodplain. Other NHS assets located in the 100-year floodplain include 8 bridges, 3 culverts, and 3 other structures.

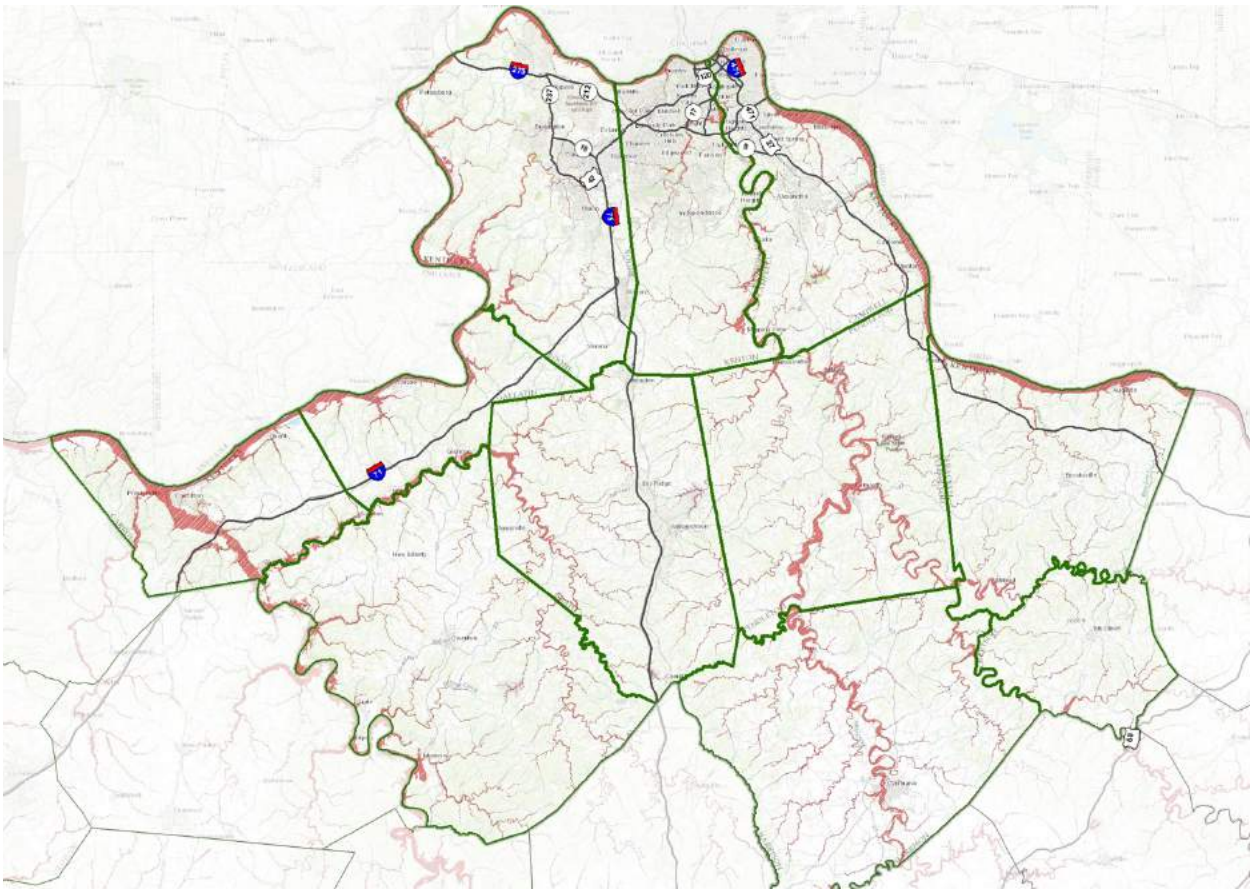


Figure 6-3. KYTC District 6; location of 100-year floodplain

From 1981 to 2015, counties in District 6 experienced extreme rainfall events (greater than 3" of rain in a single calendar day) on average every three to six years. This compares to the statewide average of an extreme rainfall event every four years. Over this time period, Carroll, Gallatin, and Boone Counties averaged the highest number of extreme rainfall events in District 6, while Grant, Harrison, and Robertson Counties experienced the fewest.

6.2.3. Landslide

Landslides are a common occurrence and are a considerable hazard in District 6. Figure 6-4 identifies areas in the district that are susceptible to landslides and where landslides have occurred historically. As depicted by Figure 4, areas along the Ohio River Valley on the northern perimeter of District 6 are particularly vulnerable to landslides. KGS documented landslides are abundant in Northern Kentucky, particularly Campbell and Kenton Counties, but also in Boone, Grant, Gallatin, and Carroll Counties. Nearly all NHS roadways in District 6 have documented landslides, including I-75 in Grant, Boone, and Kenton Counties; I-71 in Carroll, Gallatin, and Boone Counties; and I-275 in Boone, Kenton, and Campbell Counties.

In all, District 6 has 130 miles of NHS highway located in areas identified by USGS as having high landslide incidence. Of these, 75 are interstate miles, 8 are US highway miles, and 47 are KY highway miles. Other NHS assets located in these areas of high landslide incidence include 15 bridges, 2 culverts, and 65 other NHS structures.

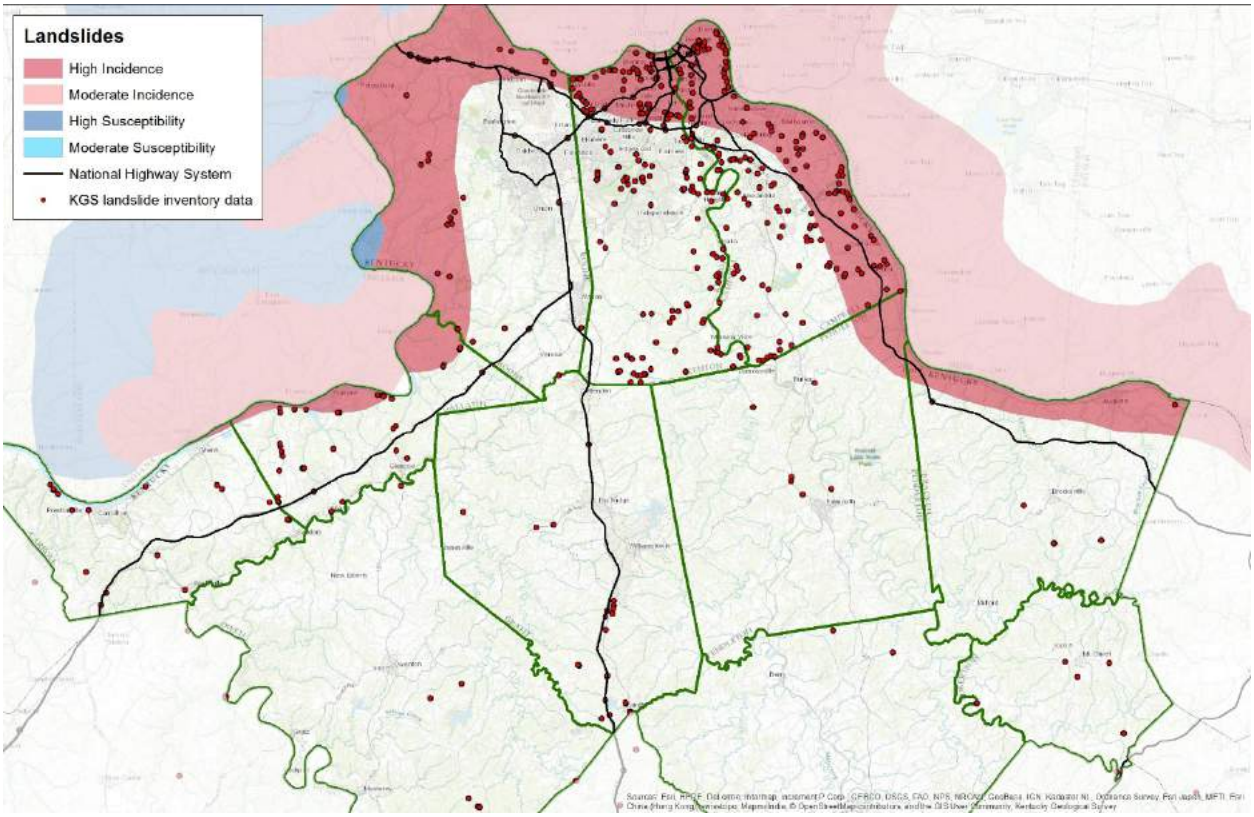


Figure 6-4.KYTC District 6 landslide susceptibility and incidences

Within the KGS landslide inventory database, landslides have been documented at the following locations along the NHS:

- I-71 approach embankment landslides at Twin Bridges over Mill Creek Road; Carroll County.
- 6 landslide locations along I-71 between MP 39 and MP 44; Carroll County.
- I-71 landslide, L-001-2009 closed due to the landslide being repaired; Gallatin County.
- Nineteen embankment landslide corrections on I-71 between MP 70 to MP 78; Boone County.
- Landslide above I-75 roadway, small slide in roadway embankment MP 161; Grant County.
- Five landslides at I-75 MP 146.9 (northbound, spring in area that was cut and filled) MP 145.4, MP 151.2, MP 152.2, MP 146.9; Grant County.
- Multiple embankment failures along I-75 MP 152-186; Boone County.
- Landslide I-75 located at Steven Hills Church; Boone County.
- Embankment landslide I-75 at MP 185.8 (north and southbound); Kenton County.
- Landslide I-75 at MP 189.9 above roadway; Kenton County.
- Landslides I-275 at MP 12.54 WB, MP 12.45 WB, MP 11.95 WB, MP 11.98 EB, MP 11.72 EB, MP 11.28 WB, MP 10.79 WB, MP 8.62 EB; Boone County.
- Landslide correction I-275 at MP 3.4 EB; Boone County.
- Eight landslides along I-275 at MP 3.3 to MP 5.9; Boone County.
- Construction landslide on KY 17 near I-275 interchange; Kenton County.

- Landslide I-275 at MP 6 to MP 7.3; Kenton County.
- Landslide correction on KY 18 MP 12.6, Boone County.
- Landslide KY 1120; Campbell County.
- Embankment slide I-275; Campbell County.
- Landslide KY 8 MP 16.6; Bracken County.

6.2.4. Karst

Sinkholes are a moderate hazard in District 6. As Figure 6-5 shows, areas of moderate karst potential are distributed throughout the District, while areas of higher karst potential are found in Harrison County, as well as the southern parts of Owen, Grant, Pendleton, Bracken, and Robertson Counties. The majority of KGS-documented sinkholes in District 6 are located in these areas of higher karst potential.

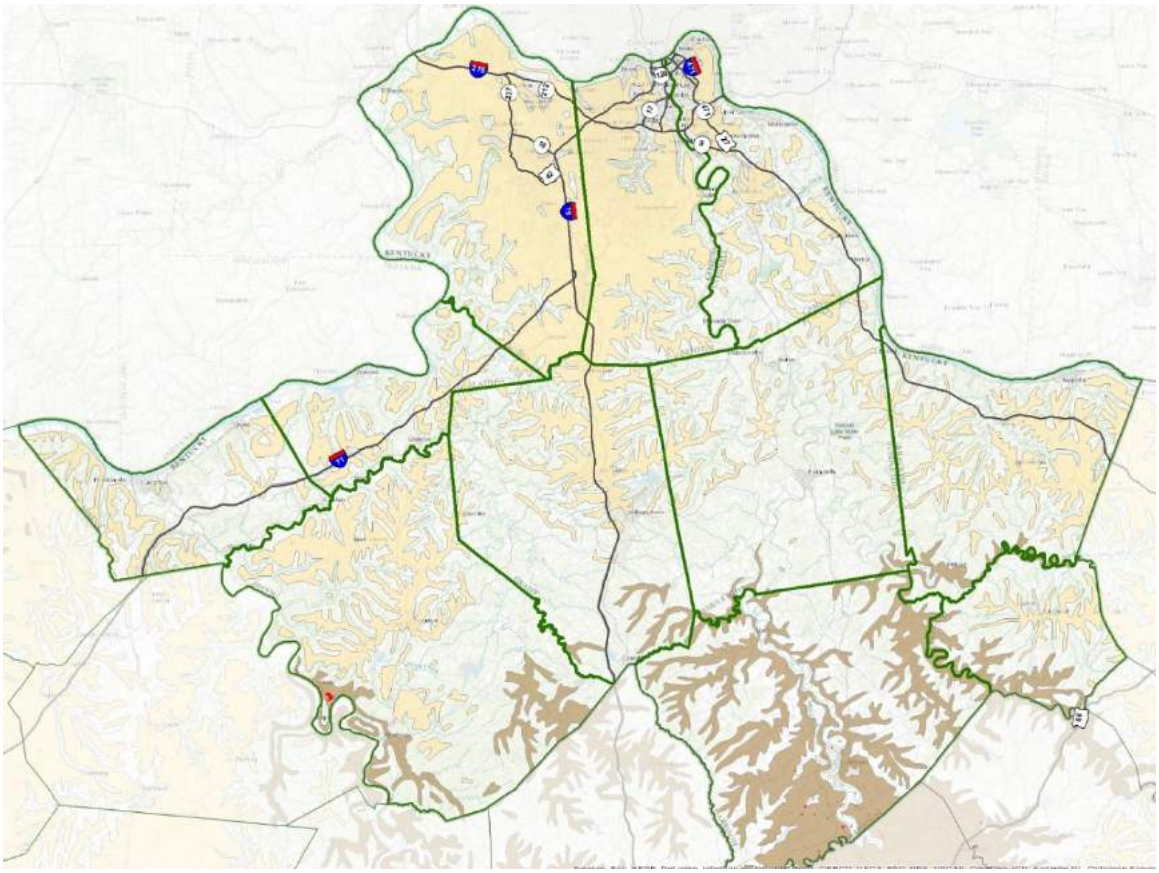


Figure 6-5. Karst potential and sinkholes in KYTC District 6

District 6 has less than one mile of NHS highway located in areas of high karst potential: this being a brief section of US-68 in southeastern Robertson County. In terms of moderate karst potential, District 6 has 223 miles of NHS highway, including 173 interstate miles, 11 US highway miles, and 39 KY highway miles. Other NHS assets located in areas of moderate karst potential include 0 bridges, 3 culverts, and 67 other structures.

6.2.5. Other Meteorological Hazards

- Snow/Ice: All areas of District 6 average between 12" and 14" of annual snowfall. These average snowfall totals are similar to those throughout the northern and central parts of Kentucky.
- Freeze/thaw: District 6 counties average between 79 and 89 annual freeze/thaw days. Boone, Kenton, and Campbell Counties average the fewest such days, likely a result of the urban heat island effect. Counties to the south of the district, including Owen and Harrison, average the most annual freeze/thaw days in the district.
- Extreme heat: All District 6 counties average at or just below 3 days annually where the temperature exceeds 95 degrees Fahrenheit. This falls below the statewide average of 4 such days annually.
- Drought/wildfire: Wildfires are uncommon occurrences in District 6. From 2002-2015, USGS documented no wildfire events in District 6.
- Tornado: District 6 has experienced fewer tornadoes than all KYTC districts outside of eastern Kentucky. From 1950 to 2015, District 4 had 31 tornadoes overall, and 7 F3 to F5 tornadoes. In 1974, District 6 experienced one of only two F5 tornadoes ever documented in the state, when a powerful tornado ripped through Boone County.

6.3.Workshop

The research team conducted a facilitated workshop in District 6 in January 2017. Fourteen KYTC personnel attended the workshop. During this workshop, data were collected from participants through a series of facilitated events, including: 1) two keypad exercises where participants were asked to score the criticality of the roadway and the potential impacts of an extreme weather and/or natural hazard event, 2) a mapping exercise with a focused conversation to contextualize flooding events in the District, and 3) a consensus workshop where participants identified and discussed challenges to performing transportation system maintenance.

6.3.1. Polling Results

For workshop exercises, the NHS was divided into 30 segments based upon road designation and county location. Participants were provided with keypads and asked to evaluate each of the NHS segments for criticality and potential impacts from extreme weather and natural hazards. An overall vulnerability score for each segment was computed by multiplying together the criticality and impacts ratings. The vulnerability score, then, provided a metric for identifying highway segments that are both the most important and could potentially suffer the most damage from natural hazards. Table 6-2 displays the results of the workshop keypad assessments. The final column ranks each segment by the vulnerability score.

Table 6-2. KYTC District 6 workshop polling results showing criticality, impacts, and vulnerability

Segment ID	Segment Description	Criticality	Impacts	Vulnerability	Rank
1	I-71: Carroll County	7.7	5.7	43.6	12
2	I-71: Gallatin County	7.8	5.3	41.2	15
3	I-71: Boone County southwest of the split	8.1	5.1	41.1	16
4	I-75: Grant County	8.2	5.5	44.8	11
5	I-75: Kenton & Boone County south of the split	8.5	5.8	48.8	10
6	I-71/I-75: Boone & Kenton County south of I-275	8.9	5.8	51.1	9
7	I-71-I-75: Kenton County north of I-275	8.9	7.1	62.7	4
8	I-71/I-75: Brent Spence Bridge & approach	9.0	8.2	73.4	1
9	I-275: west of KY 237 & Carroll C. Cropper Bridge	8.0	6.4	51.3	8
10	I-275: from I-71/I-75 to KY 237	8.4	6.3	52.4	7
11	I-275: from I-71/I-75 to I-471	8.4	7.0	58.7	5
12	I-275: east of I-471 & Combs-Hehl Bridge	8.3	7.7	63.7	3
13	I-471: Daniel C Beard Bridge	8.8	7.7	67.1	2
14	I-471	8.3	7.0	57.8	6
15	KY 237: N Bend Rd/Camp Ernst Rd/Pleasant Valley Rd	6.2	5.0	31.2	25
16	US 42: I-71/I-75 to Pleasant Valley Rd	6.7	5.3	35.7	17
17	KY 18: Burlington Pike from I-71/I-75 to N Bend Rd	6.5	5.2	33.8	21
18	KY 212: Airport Access	7.0	6.1	42.6	13
19	KY 8: W 4th & W 5th St in Covington & Newport	5.7	5.8	32.7	22
20	KY 1120: 10th & 11th St in Covington & Newport	5.3	5.6	29.6	27
21	John A Roebling Bridge and approach	6.0	5.8	34.5	19
22	KY 17: Greenup St, Scott Blvd, Madison Ave	5.7	5.1	28.9	28
23	Taylor Southgate Bridge and approach	5.9	5.4	32.1	24
24	US 27: Monmouth & York St, Alexandria Pk to I-471	6.2	5.5	34.3	20
25	KY 16: Decoursey, Winston, Taylor Mill N of I-275	5.5	5.0	27.5	29
26	US 27: Alexandria Pike from I-275 to N AA Hwy	6.8	5.2	35.4	18

27	KY 9: AA Hwy in Campbell County	7.2	5.9	42.3	14
28	KY 9: AA Hwy in Pendleton County	6.2	5.2	32.2	23
29	KY 9: AA Hwy in Bracken County	5.9	5.3	31.1	26
30	US 68: Robertson County	4.6	3.8	17.2	30

6.3.2. Map Exercise

Workshop participants were asked to review and mark-up eight detailed maps of the NHS in District 6. The maps included NHS roadway segments and the associated bridges, culverts, and other structures; other state highways; streams, rivers, and other bodies of water; and the 100-year floodplain. Participants were asked to mark the maps and provide as much detail as possible for areas along the NHS that have 1) flooded in the past, 2) have been close to flooding in the past, and 3) are likely to flood during an extreme weather event. Table 6-3 displays the results of this exercise.

Table 6-3. District 6 NHS segments and flood

District	County	MP	Route	Hazard	Intersecting feature
6	Campbell	1.42	KY-8	Has flooded	
6	Campbell	0	US-27	Has flooded	
6	Kenton	0	I-75	Has flooded	I-75 Ramp Exit 184
6	Carroll	0	I-71	Has flooded	Ramps from KY-0227 to I-71
6	Carroll	43.5	I--71	Has nearly flooded	
6	Grant	155.2	I--75	Has nearly flooded	
6	Kenton	185.7	I--71	Has flooded	Close to I-275
6	Kenton	0	I-275	Has flooded	I-275 to I-75 ramp
6	Kenton	187.7	I--75	Has flooded	
6	Boone	176.1	I--75	Has flooded	
6	Campbell	76.7	I--275	Has flooded	
6	Kenton	191.15	KY-8	Has flooded	
6	Kenton	190.55	KY-1120	Has flooded	near I-75
6	Campbell	19.6	US-27	Has flooded	
6	Kenton	19.6	KY-17	Has nearly flooded	
6	Kenton	14.5	KY-16	Has nearly flooded	

6.3.3. Workshop discussion

Landslides and flooding cause major problems throughout District 6. Widespread flooding in 1997 affected many areas of the district. Nearly the entire town of Falmouth in Pendleton County was submerged as the Licking River flowed well over its banks. Areas of northern Kentucky along the Ohio River that were not well-protected by a floodwall were also submerged, including Bellevue and Silver Grove in Campbell County. In Carroll County, backwater flow from the confluence of the Kentucky River and Ohio River led to flooding on I-71 at Exit 44. Ramps at this exit were submerged and closed to traffic for 3-4 days. In Newport, storm sewer systems were overwhelmed, causing flooding on KY-8 and US-27.

In addition to causing flooding, heavy rainfall events can also trigger landslides in District 6. At the workshop, KYTC personnel reported that pretty much anywhere in the district where a road is located near a stream or river, landslides are possible. Areas along the Ohio River are particularly vulnerable to landslide, especially in Campbell County. KYTC officials believe that KY-8 along the bluffs of the Ohio River in Campbell County will eventually fall due to flooding-induced

landslides. Also in Campbell County, officials described a large recurring slide along I-275 near the Combs-Hehl Bridge.

District personnel expressed concern with the Brent Spence Bridge and approach in Kenton County. At the workshop, personnel noted geologic instability near one of the piers. Given the importance of this interstate bridge to the region, district personnel felt it critical to address any potential problems with the bridge and approach.

6.3.4. Roadways outside of the NHS that flood

District personnel reported multiple state-maintained roads that have flooded in the past. KY-2951 in Boone County flash floods on a regular basis. KY-1303 in Kenton County similarly flash floods, and was recently closed for over a day due to flooding. In Covington, KY-1120 floods near I-75, as the culverts are undersized and unable to handle large flows. Similarly, the AA Highway north of I-275 in Campbell County has flooded due to culverts being blocked by debris. The intersection of KY-10 and KY-1996 in Campbell County also floods frequently, resulting in road closures that can last hours or days. In 2010, KY-467 between Sparta and Glencoe in Gallatin County was washed out by flood. In 2011, KY-617 in Robertson County was washed out around the Turkey Creek culvert by flooding water. These culverts had just been installed two years earlier to address problems with flooding.

6.3.5. Maintenance facilities flooding

No workshop participants recalled any of the KYTC maintenance facilities flooding in the past, though the facilities in Carroll County were said to have come close to flooding.

6.3.6. Consensus workshop

After the discussion of major flooding events, workshop participants engaged in a consensus workshop. The participants were asked to individually brainstorm about the following question; "What are the Greatest Challenges to Performing Maintenance in District 6?" Participants were asked to work in small groups to discuss and clarify their ideas. Ideas were then presented and group with all the participants. Table 6-4 provides the participants answers to the consensus workshop question.

Table 6-4. Results of District 6 consensus workshop

Identified Challenges to Conducting Maintenance Operations in District 6							
Adding Mileage to the System	**Appropriate Flow of Money to Address...**	**Fighting Mother Nature**	**More Qualified Personnel**	**Need More Money**	**Minimize Outside Influence**	**Better, Updated, Newer Equipment**	**Urban vs. Rural Divide**
Political Help	More Infrastructure	Condition and Topography	Personnel	Budget	Public Input	Equipment	Different Philosophies across District
	Old Pipes and Culverts	Slide Repairs	Personnel, Hiring	Funding	Public Expectations	Equipment	Fixing Roads instead of patching
	Old Pipes	Topography/Geology	Crew Size on a given Day	Money	Meeting Public Expectations	Equipment	
	Age of infrastructure	Location of Roads	Adequate Staffing	Budget, Money	Dealing with Traffic	Equipment	
		Trees	Crew Size	Funding for Slide repairs			
			Personnel	Money			
			Personnel, Experience	Money			
			Man Power	Sufficient Budget			
			Personnel				

6.4.Results

6.4.1. Identification of most at vulnerable assets

Table 6-5 lists District 6 NHS assets with a vulnerability score of 3.5 or greater for any of the four major hazards in this analysis (a full list of District 6 NHS assets and vulnerability scores is in Appendix 2). Flood and landslide are the two hazards that cause the greatest vulnerabilities in District 6. I-471 in Campbell County is scored as having the greatest vulnerability to flooding, while I-471 in Campbell County and I-275 in Campbell are scored as having the greatest vulnerability to landslides. These results are similar to those from the keypad scoring at the District 6 insofar as I-471 and I-275 being among the most vulnerable assets in the district. Workshop participants scored the I-75 Brent Spence Bridge in Kenton County as the single most vulnerable asset in the district, and it also showed up in the overall analysis as being highly vulnerable to both flooding and landslide.

Table 6-5. District 6 NHS assets with vulnerability score 3.5 or greater

District	County	Route	Vulnerability Score	Hazard
6	Campbell	I-275	**3.54**	Flood
6	Kenton	I-75	**3.54**	Flood
6	Carroll	I-71	**3.62**	Flood
6	Campbell	I- 471	**3.71**	Flood
6	Carroll	I-71	**3.52**	Landslide
6	Gallatin	I-71	**3.52**	Landslide
6	Campbell	KY 9	**3.63**	Landslide
6	Boone	I-275	**3.72**	Landslide
6	Kenton	I-275	**3.73**	Landslide
6	Kenton	I-75	**3.73**	Landslide
6	Campbell	I- 471	**3.80**	Landslide
6	Campbell	I-275	**3.80**	Landslide

6.4.2. Worst case scenario

Because of the interconnectedness between northern KY and southern OH, any flood or landslide that damaged the Ohio River bridges or approaches would be the worst case scenario. The topography of this area of northern Kentucky near the river is very steep, hilly, and vulnerable to landslides. The worst case scenario would be a major regional rain event that resulted in both localized flash flooding as well as Ohio River flooding. Flooding of this nature could ultimately lead to slope destabilization and trigger numerous landslides. Given the high landslide susceptibility of the area, transportation assets would potentially be at risk. Workshop attendees were most concerned about the Brent Spence Bridge (I-75), the Combs-Hehl Bridge (I-275), and the Daniel C. Beard Bridge (I-471), all of which facilitate regional mobility and enhance economic opportunities.

7. KYTC District 7

7.1.District Overview

KYTC District 7 is geographically located in central Kentucky and includes Anderson, Bourbon, Boyle, Clark, Fayette, Garrard, Jessamine, Madison, Mercer, Montgomery, Scott and Woodford counties. Lexington, located in Fayette County, is the second largest city in Kentucky, with a population of just over 300,000[20]. Rivers located in District 7 include the Kentucky River, Salt River, Dix River, Red River, North Rolling Fork, and South Fork Licking River. The majority of District 7 is located in the Inner Bluegrass geological region which is characterized by rolling hills, fertile soils, and karst topography. Parts of the southeast region are located in the Knobs area of the Outer Bluegrass Region, which is characterized by isolated, steep sloping, and often cone-shaped hills.

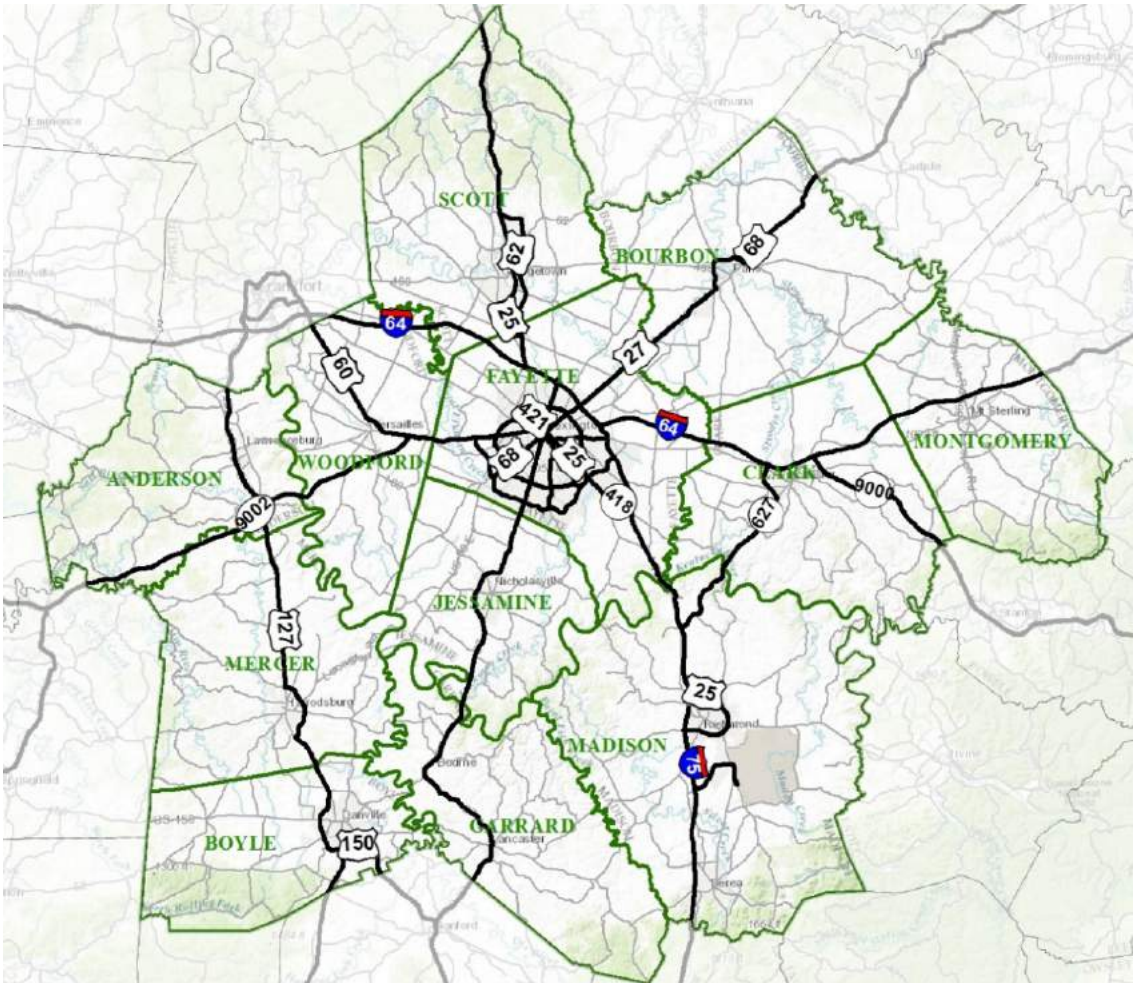


Figure 7-1. KYTC District 7 NHS

District 7 NHS is comprised of 803 miles of roadway, which is the most of any district in the state (for divided highways, centerline miles are doubled in this total). District 7 NHS includes two

[20] U.S. Census Bureau, Population Division.

major interstates, I-64 and I-75, as well as several parkways: Bluegrass Parkway (BG-9002) and Bert T. Combs Mountain Parkway (KY-9000). US Highways in the district that are a part of the NHS include US-127, US-150, US-25, US-27, US-60, US-62, and US-68. Other District 7 NHS assets include 58 bridges, 47 culverts, and 184 structures.

7.2.Hazards

District 7 NHS assets, including highway segments, bridges, culverts, and other structures were assessed against the four primary hazards identified for this project: earthquake, flood, sinkhole, and landslide. Table 7-1 summarizes the relationship between these NHS assets and selected natural hazard indicators.

Table 7-1. Summary of KYTC District 7 NHS assets and natural hazard indicators

Asset Type	D7 Total	PGA ≥ 60 (Destructive)	PGA ≥ 30 and < 60 (Very Strong)	PGA ≥ 18 and < 30 (Strong)	In Flood Plain	Major Karst	Moderate Karst	High Landslide Susceptibility	Moderate Landslide Susceptibility
Total Road Miles	803	0	0	0	10	526	111	14	15
Interstate	281	0	0	0	1	156	66	14	0
Parkway	84	0	0	0	0	29	0	0	0
US Highway	294	0	0	0	6	230	21	0	15
KY Route	108	0	0	0	3	83	24	0	0
Local Road	35	0	0	0	0	28	0	0	0
Bridges	58	0	0	0	35	43	10	0	0
Culverts	47	0	0	0	28	41	2	1	1
Structures	184	0	0	0	4	127	14	2	2

7.2.1. Earthquake

District 7 does not lie in close proximity to high hazard seismic zones and is not particularly vulnerable to earthquakes. Figure 7-2 shows where District 7 lies relative to USGS defined PGA zones. The majority of District 7 lies in PGA Zone 8. Parts of Anderson, Mercer, Boyle, Woodford, and Scott are in PGA Zone 6, which is the lowest zone found in Kentucky. Most of Montgomery and the eastern tip of Bourbon County are in PGA Zone 10. PGA zones in the district align on the Modified Mercalli Scale to "Slightly Strong" and seismic activity at this level would not be expected to cause major damage and negative impacts to NHS assets in District 7.

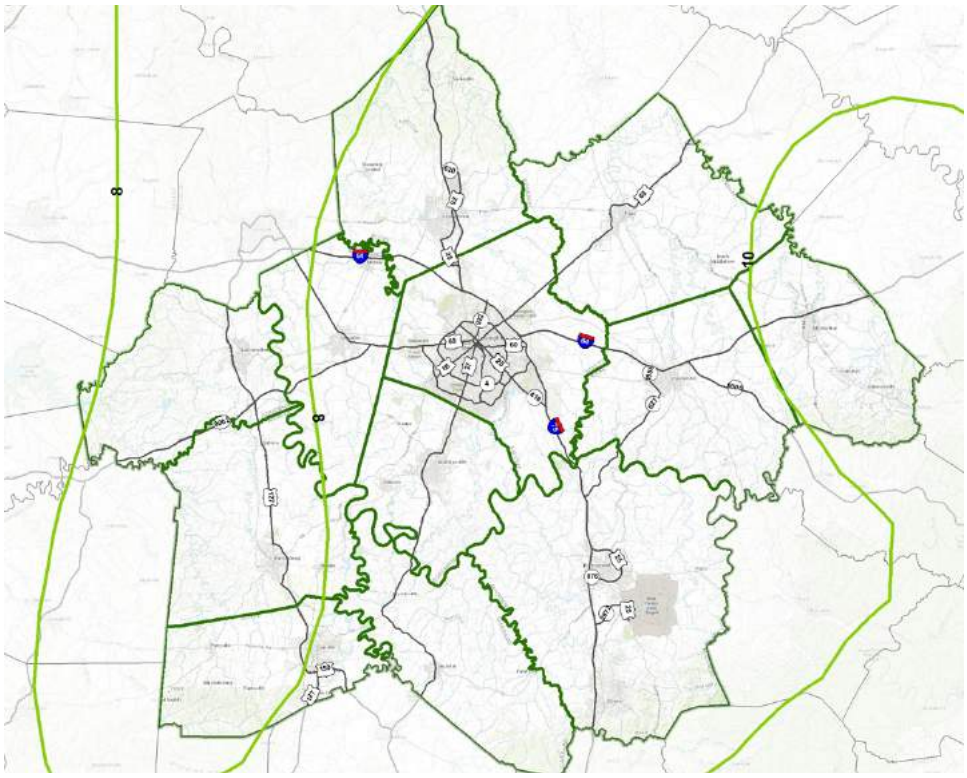


Figure 7-2.USGS PGA Zones in KYTC District 7

7.2.2. Flood

The majority of District 7 is drained by the Kentucky River basin system, which flows north toward the Ohio River. Bourbon, Montgomery and parts of Clark County are drained by the Licking River system, while western Anderson, Mercer, and Boyle County are drained by the Salt/Rolling Fork river system. In total, District 7 has 10 miles of NHS roadway located in the 100-year floodplain. Other NHS assets located in the 100-year floodplain are 35 bridges, 28 culverts, and 4 other structures. The District has not experienced any flooding emergency relief events since 2009.

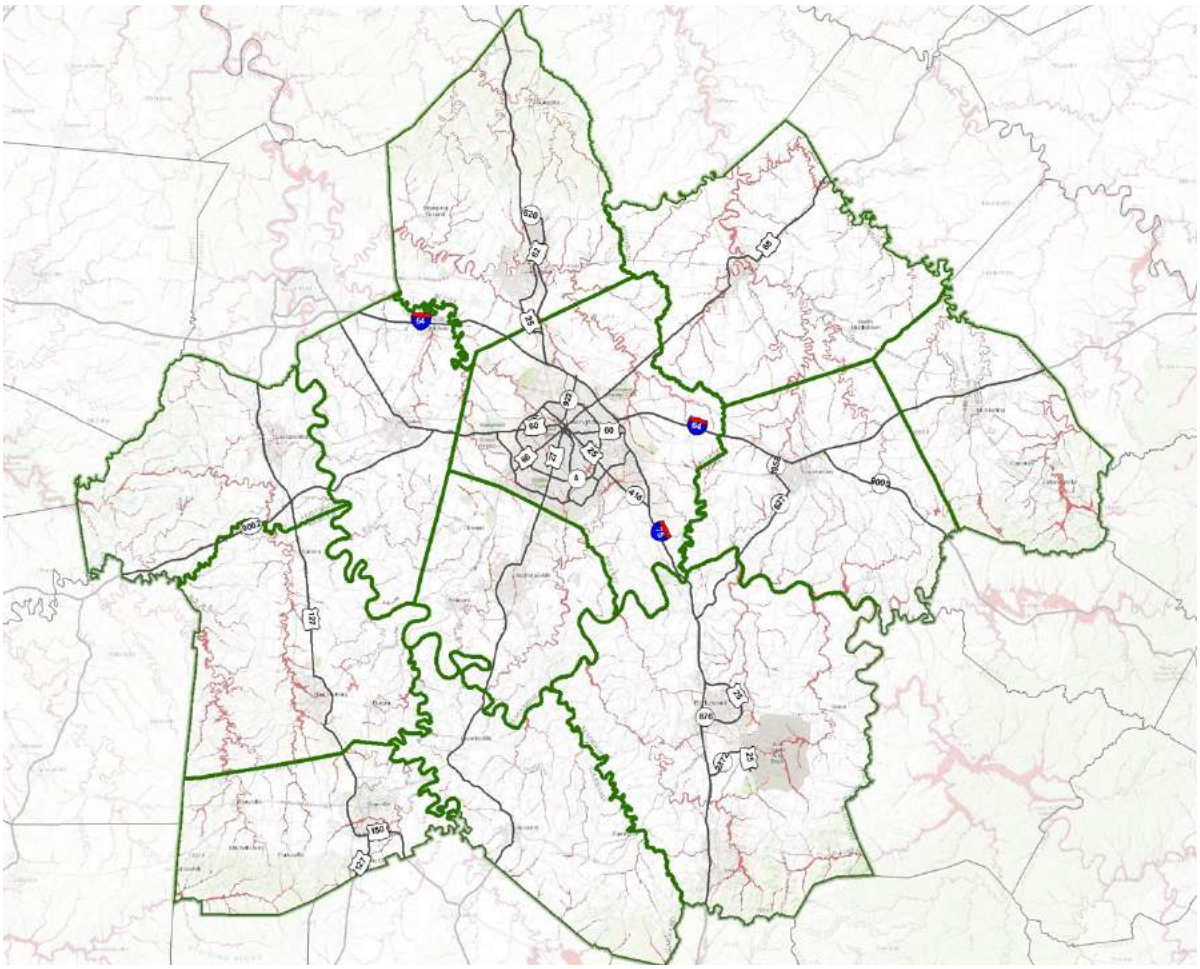


Figure 7-3. KYTC District 7; location of 100-year floodplain

From 1981 to 2015, counties in District 7 experienced extreme rainfall events (greater than 3" of rain in a single calendar day) on average every four to eight years. This compares to the statewide average of an extreme rainfall event every four years. In general, the likelihood of experiencing such extreme rainfall events decreases moving south and eastward in the district.

7.2.3. Landslide

There are only a few areas in District 7 that are vulnerable to landslide, with majority of the district having flat or gently sloping topography. Southern areas of the district, including Boyle County, southern Garrard, Madison, and Montgomery County are located in areas with moderate landslide vulnerability, as the region transitions from the Inner Bluegrass into Cumberland Plateau.

District 7 has 14 miles of NHS highway located in the southern part of Madison County that have been identified by USGS as having high landslide incidences. Additional District 7 NHS assets located in high landslide incidence areas include one culvert and two other NHS structures. District 7 has not experienced any landslide-related emergency relief events since 2009.

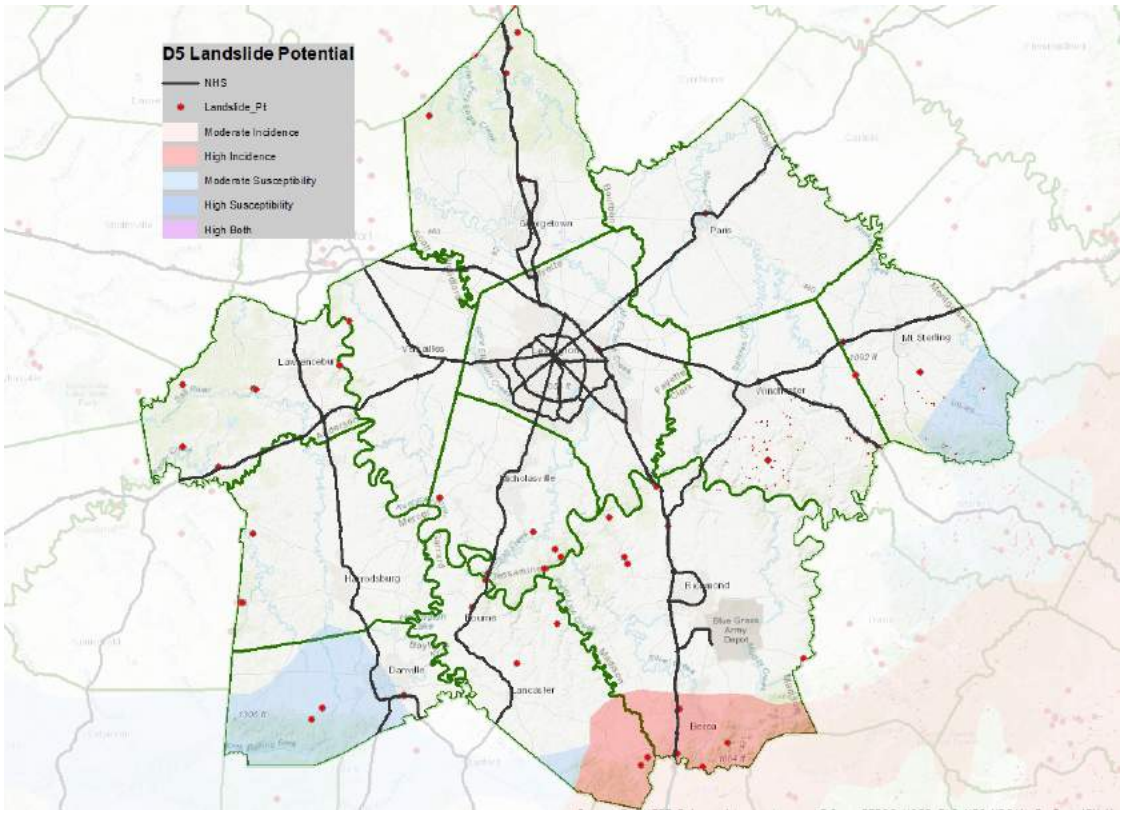


Figure 7-4.KYTC District 7 landslide susceptibility and incidences

Within the KGS landslide inventory database, landslides have been documented at the following locations along the NHS:

- Construction failure on Danville Bypass US 150B; Boyle County.
- Landslide KY 620 MP 1.024; Scott County.
- Eight landslides I-75 at MP 133 to MP 143; Scott County.
- Construction landslide I-75 SB MP 97 to MP 111; Fayette County.
- Rockfall US-27; Jessamine County.
- Rockfall US-27; Garrard County.
- Landslide US-27 MP 13.5; Garrard County.
- Landslide US-27 MP 1.1; Bourbon County.
- Cut slope failure correction KY 9000 MP 3 to MP 12; Clark County.
- Slide correction KY 974 between MP 19 and MP 21; Clark County.
- Embankment landslide correction I-75 MP 93.8 NB; Madison County.
- Landslide I-64 MP 104.6; Montgomery County.

7.2.4. Karst

Sinkholes are a significant hazard in District 7. As Figure 7-5 depicts, there are areas of major karst potential in the central area of the district, including Fayette, Woodford, Bourbon, Scott, Jessamine, Clark, Mercer, and Boyle Counties. Sinkholes are common in these areas of high karst potential. However, the threat to the highway system associated with these sinkholes is lower than

that in southern areas of Kentucky, due to the specific geologic formations associated with the two areas.

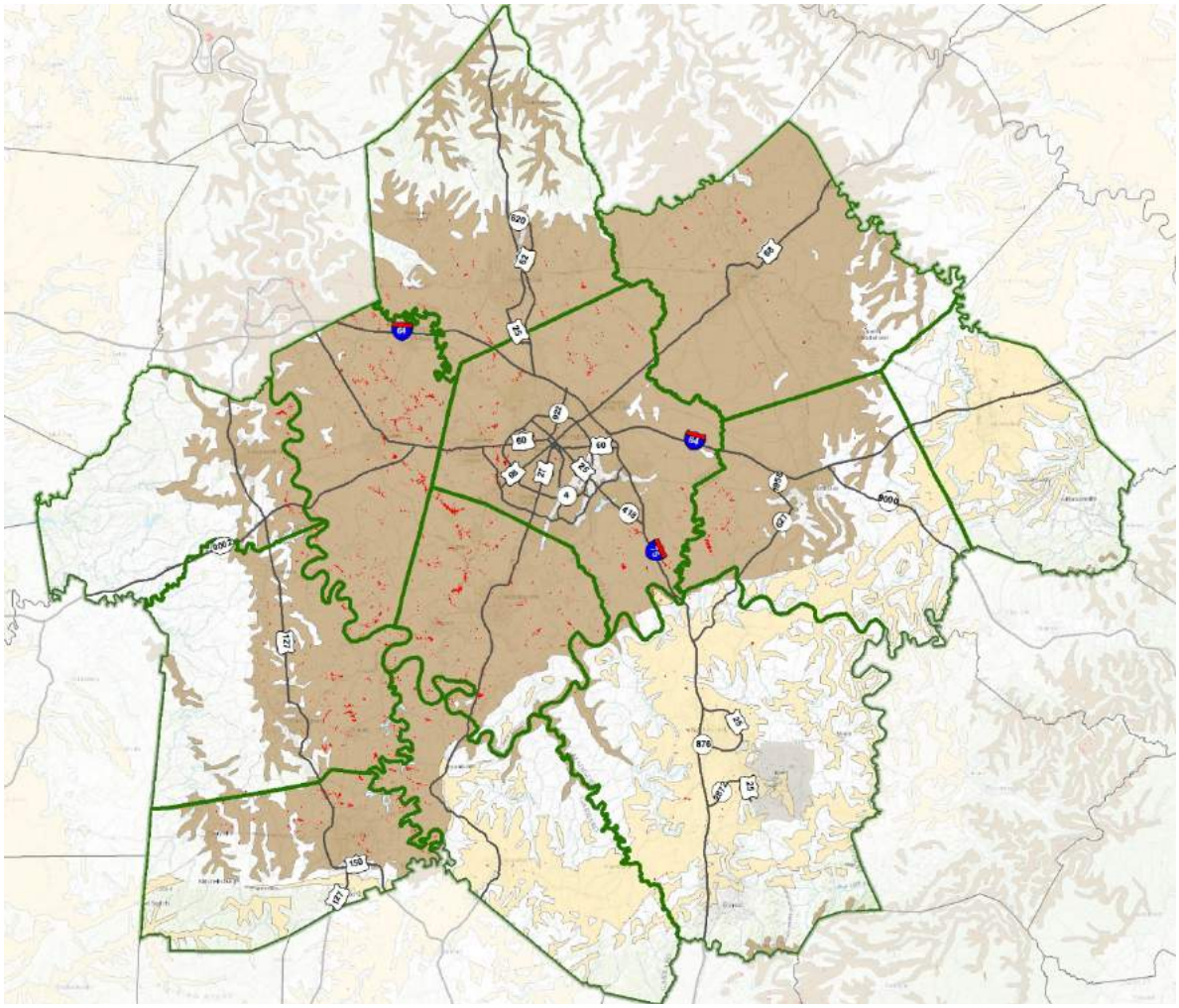


Figure 7-5. Karst potential and sinkholes in KYTC District 7

District 7 has 526 miles of NHS highway located in areas of high karst potential, including 156 interstate miles and 29 parkway miles. District 7 has another 111 miles of NHS highway located in areas of moderate karst potential. NHS structures located in areas of major karst potential include 43 bridges, 41 culverts, and 127 other structures.

7.2.5. Other Meteorological Hazards

- Snow/Ice: All areas of District 7 average between 10" and 14" of annual snowfall. These average snowfall totals are similar to those throughout the northern and central parts of Kentucky.
- Freeze/thaw: District 7 counties average between 77 and 86 annual freeze/thaw days, which compares similarly to the state average of 84 days.
- Extreme heat: All District 7 counties average just below 3 days annually where the temperature exceeds 95 degrees Fahrenheit. This is fewer than the statewide average of 4 such days annually.

- Drought/wildfire: Wildfires are rare across the majority of District 7. Wildfire vulnerability is somewhat higher in the southeastern areas of the district, especially within the Daniel Boone National Forest in Madison, Clark, and Montgomery County.
- Tornado: Compared to the other 12 KYTC Districts in Kentucky, District 7 has average vulnerability to tornadoes. From 1951 to 2015, District 7 experienced the seventh most overall tornadoes (49) and the seventh most F3 to F5 tornadoes (7) in Kentucky.

7.3.Workshop

The research team conducted a facilitated workshop in District 7 in March 2017. Thirteen KYTC personnel attended the workshop. During the workshop, data was collected from participants through a series of facilitated events, including: 1) two keypad exercises where participants were asked to score the criticality of the roadway and the potential impacts of an extreme weather and/or natural hazard event, 2) a mapping exercise with a focused conversation to contextualize flooding events in the District, and 3) a consensus workshop where participants identified and discussed challenges to performing transportation system maintenance.

7.3.1. Polling Results

For workshop exercise purposes, the NHS in District 7 was divided into 40 functional segments based upon road designation and county location. Participants were provided with keypads and asked to evaluate each of the NHS segments for criticality and potential impacts from extreme weather and natural hazards. An overall vulnerability score for each segment was computed by multiplying together the criticality and impacts ratings. The vulnerability score, then, provided a metric for identifying highway segments that are both the most important and could potentially suffer the most damage from natural hazards. Table 7-2 displays the results of the workshop keypad assessments. The final column ranks each segment by the vulnerability score.

Table 7-2. District 7 workshop polling results showing criticality, impacts, and vulnerability

Segment ID	Segment Description	Criticality	Impacts	Vulnerability	Rank
1	US 127: Anderson County	6.3	4.4	27.7	25
2	Bluegrass Parkway: Anderson/Mercer County	7.9	5.9	46.6	7
3	US 127/US 127B: Mercer County	5.4	4.2	22.7	30
4	US 127/US 127B: Boyle County	5.8	4.0	23.2	29
5	US 150/US 150B: Boyle County south of Danville	5.4	3.7	20.0	35
6	I-64: Woodford/Scott/Fayette west of the split	8.4	5.6	47.0	6
7	US 60: Woodford County	6.7	4.2	28.1	23
8	Bluegrass Parkway: Woodford County	7.6	6.0	45.6	8
9	US 62/KY 3487/KY 620: Cherry Blossom Way & McClelland Cir	6.2	3.5	21.7	31
10	US 25/KY 1973: Lexington Rd to I-75 in Scott Cty	4.9	3.5	17.2	38
11	I-75: Scott County north of US 62	8.5	6.3	53.6	5
12	I-75: Scott & Fayette County north of the split	8.8	6.8	59.8	3
13	I-64/I-75: Fayette County	8.9	6.5	57.9	4
14	I-75: Fayette County south of the split	8.8	7.3	64.2	2
15	I-64: Fayette County east of the split	8.3	4.8	39.8	9
16	KY 4: New Circle Rd expressway	7.6	4.5	34.2	12
17	KY 4: New Circle Rd (Richmond Rd to Newtown Pk)	6.8	4.1	27.9	24
18	KY 922: Newtown Pike	6.8	4.3	29.2	20
19	US 421/KY 1681: Leestown Rd inside New Circle	5.6	3.6	20.2	34
20	US 60: Versailles Rd	6.9	4.5	31.1	18
21	US 68: Harrodsburg Rd & S Broadway	6.6	4.3	28.4	21
22	US 27: Nicholasville Rd, S Limestone & S Upper	7.5	4.5	33.8	13
23	KY 1974: Tates Creek Rd to Man O War	5.4	3.9	21.1	32
24	US 25/KY 418: Main St/Vine St/Richmond Rd/Athens-Boonesboro Rd	7.3	4.2	30.7	19
25	US 60: Winchester Rd	6.7	3.8	25.5	27

Segment ID	Segment Description	Criticality	Impacts	Vulnerability	Rank
26	US 27: N Broadway and Paris Pike	6.8	3.6	24.5	28
27	US 60: High and Maxwell St	5.7	2.8	16.0	39
28	Man O War Blvd	6.8	3.8	25.8	26
29	US 27: Jessamine County from KY 3374 to Fayette County line	7.0	4.7	32.9	16
30	US 27: Jessamine County from KY 3374 to Garrard County line	6.2	5.1	31.6	17
31	US 27: Garrard County	5.5	6.1	33.6	15
32	US 68: Bourbon County from US 27 to Nicholas County line	5.8	3.6	20.9	33
33	US 27: Bourbon County from US 68 to Fayette County line	6.3	3.0	18.9	37
34	I-64: Clark County	8.0	4.2	33.6	14
35	KY 627/KY 1958: Boonesboro Rd and Winchester bypass	6.0	4.7	28.2	22
36	Mountain Parkway: Clark County	6.9	5.4	37.3	10
37	I-75: Madison County	8.7	7.4	64.4	1
38	US 25/KY 876: Richmond Eastern Bypass	5.6	3.5	19.6	36
39	US 25/US 421/KY 2872: Blue Grass Army Depot access	5.2	2.3	12.0	40
40	I-64: Montgomery County	7.7	4.8	37.0	11

7.3.2. Map Exercise

Workshop participants were asked to review and mark-up eight detailed maps of the NHS in District 7. The maps included NHS roadway segments and the associated bridges, culverts, and other structures; other state highways; streams, rivers, and other bodies of water; and the 100-year floodplain. Participants were asked to mark the maps and provide as much detail as possible for areas along the NHS that have 1) flooded in the past, 2) have been close to flooding in the past, and 3) are likely to flood during an extreme weather event. Table 7-3 displays the results of this exercise.

Table 7-3. District 7 NHS segments and flood

District	County	MP	Route	Hazard	Intersecting feature
7	Fayette	0	KY-4	Has flooded	RR underpass on New Circle Rd
7	Fayette	0	US-68	Has flooded	RR underpass on Broadway
7	Fayette	10.66	KY-4	Has flooded	@ US-0027
7	Fayette	13.93	KY-4	Has flooded	RR Underpass By Palumbo
7	Fayette	8.38	US-27	Has flooded	RR underpass By KY4
7	Clark	4.5	KY-1958	Has flooded	Strodes Creek

7.3.3. Workshop discussion

District 7 is fairly well-off when it comes to natural hazard vulnerability. The area is somewhat prone to the development of sinkholes, but not enough to be a large concern. Landslides are infrequent and generally not impactful. Earthquakes are not a threat. The only natural hazard of concern is flash flooding, but such floods rarely impact the District 7 NHS. As Table 3 demonstrates, the majority of NHS assets affected by flood are in the urbanized area of Lexington; such assets occasionally will close due to high water.

Outside of the NHS, District 7 has had more frequent problems with flooding. District personnel described a recent flooding event from April of 2015 that impacted roads throughout the district. Among the road closures from this flooding event were:

- Fayette County: Tates Creek Rd, Leestown Rd, Old Frankfort Pk, Ironworks Rd, Newtown Pk, Georgetown Rd, Old Paris Pk, Versailles Rd, Todds Rd.
- Bourbon County: KY 460, KY-57, and KY-3364.
- Madison County: US-25 closed due to partial culvert collapse at MP 22.9.
- Montgomery County: KY-1331 closed at MP 4 due to washed out drain.
- Scott County: US 460 closed at MP 6, US 62 closed at MP 5, KY 922 closed at MP 1, KY-32 closed at MP 15 and MP 25, KY-1963 closed at MP 4, KY-620 washed out in two places.
- Woodford County: KY-1965 closed at MP 4.2, KY-1681 closed at MP 11.67.

7.3.4. Roadways outside of the NHS that flood

Besides those road closures associated with the 2015 flood, KYTC personnel identified a number of other state roads that have flooded in the past. KY-646 in Clark County floods once or twice a year. KY-169 in Madison County experienced a major flood of several feet of water over the

roadway near the confluence of Tates Creek and the Kentucky River. KY-213 in Montgomery County has had problems with flooding where water has knocked over trees that have subsequently damaged a bridge. In Garrard County, KY-1971 floods nearly every time it rains. In Anderson County, backwater from the Kentucky River can result in several feet of water over KY-1510 near the Four Roses Distillery. Also in Anderson County, KY-53 was washed out from a recent flood event. In Mercer County, US-68 near the Kentucky River Palisades floods frequently at the bridge. In Jessamine County, US-27X in Nicholasville floods due to improper drainage associated with recent land use development in the area.

Overall, district personnel reported that they often do not know about the potential flood problems until they actually occur. In this way, KYTC activities are largely reactionary in nature. They simply address any problems that arise as they occur.

7.3.5. Maintenance facilities flooding

District 7 personnel did not identify any problems with flooding at maintenance KYCT county maintenance facilities.

7.3.6. Consensus workshop

For the consensus workshop, participants were asked to individually brainstorm about the following question; "What do you need to perform successful maintenance projects in District 7?" Participants were asked to work in small groups to discuss and clarify their ideas. Ideas were then presented and group with all the participants. Table 7-4 provides the participants answers to the consensus workshop question.

Table 7-4. Results of District 7 consensus workshop

Issues Identified to Perform Successful Maintenance Projects in District 7						
Central Office and District Office Administrative Hurdles	**Re-Organization is less than ideal—Maintenance vs. Construction**	**No Motivation**	**Funds**	**Land Restraints**	**Lack of Personnel**	**Lack of Equipment**
	Lack of time for planning work	Attitude	Funds	No R/W	Personnel	Lack of Equipment
		Public Expectations	Lack of Funding	Utility Issues	Lack of experienced Maintenance staff	Process to get equipment and materials is too complicated!
			Money	Not always clearly defined R/W	Lack of Employee Experience	Scope—Lack Equipment and Material
			Budget Inadequate Funding		Lack of Experience on Equipment	
			FD05 Rating is Dumb			
			High Cost of Contract Work			

7.4.Results

7.4.1. Identification of most at vulnerable assets

Table 7-5 lists District 7 NHS assets with a vulnerability score of 3.5 or greater for any of the four major hazards in this analysis (a full list of District 7 NHS assets and vulnerability scores is in Appendix 2). Landslide is the only hazard that causes significant vulnerability in District 7, with I-64 in Montgomery County and I-75 in Madison County each having landslide vulnerability scores greater than 3.5. These results largely mirror those from the workshop keypad scoring exercise, where few assets were scored as likely to suffer considerable impacts from any of the natural hazards. In the workshop, the extent of I-75 throughout the district consistently scored as having the highest vulnerability, not so much because of any particular threat to the asset but rather simply because of the high criticality score given to the asset.

Table 7-5. District 7 NHS assets with vulnerability score 3.5 or greater

District	County	Route	Vulnerability Score	Hazard
7	Montgomery	I-64	**3.52**	Landslide
7	Madison	I-75	**3.80**	Landslide

7.4.2. Worst case scenario

District 7 is fortunate from the standpoint that it does not have any single looming threat to the transportation system. The most critical asset in District 7 is the I-75 Clays Ferry Bridge over the Kentucky River at the Fayette-Madison County line, and any threat to this asset would constitute the worst case scenario. Fortunately, the natural hazard risks associated with this bridge are fairly low. It is not particularly vulnerable to flood or landslide, and District 7 is in a low earthquake risk area.

8. KYTC District 8

8.1.District Overview

KYTC District 8 is in southern Kentucky and includes the counties of Adair, Casey, Clinton, Cumberland, Lincoln, McCreary, Pulaski, Rockcastle, Russell, and Wayne. District 8 is largely comprised of rural areas and is bordered to south by Tennessee. Rivers located in the district include the Cumberland River (and accompanying Lake Cumberland), Green River, Dix River, Big South Fork Cumberland River, and Rockcastle River. The majority of District 8 is located in the Pennyroyal geological region, which extends along the southern edge of the state from Land Between the Lakes in the west to the Appalachian Mountains in the east. The Pennyroyal region is characterized as a limestone plain dotted by thousands of sink holes, sinking streams, streamless valleys, springs, and caverns. McCreary County and the southeastern parts of Pulaski and Wayne Counties lie along the Pottsville Escarpment in the Eastern Kentucky Coalfield geological region. The northern edge of the district lies in the Outer Bluegrass geological region.

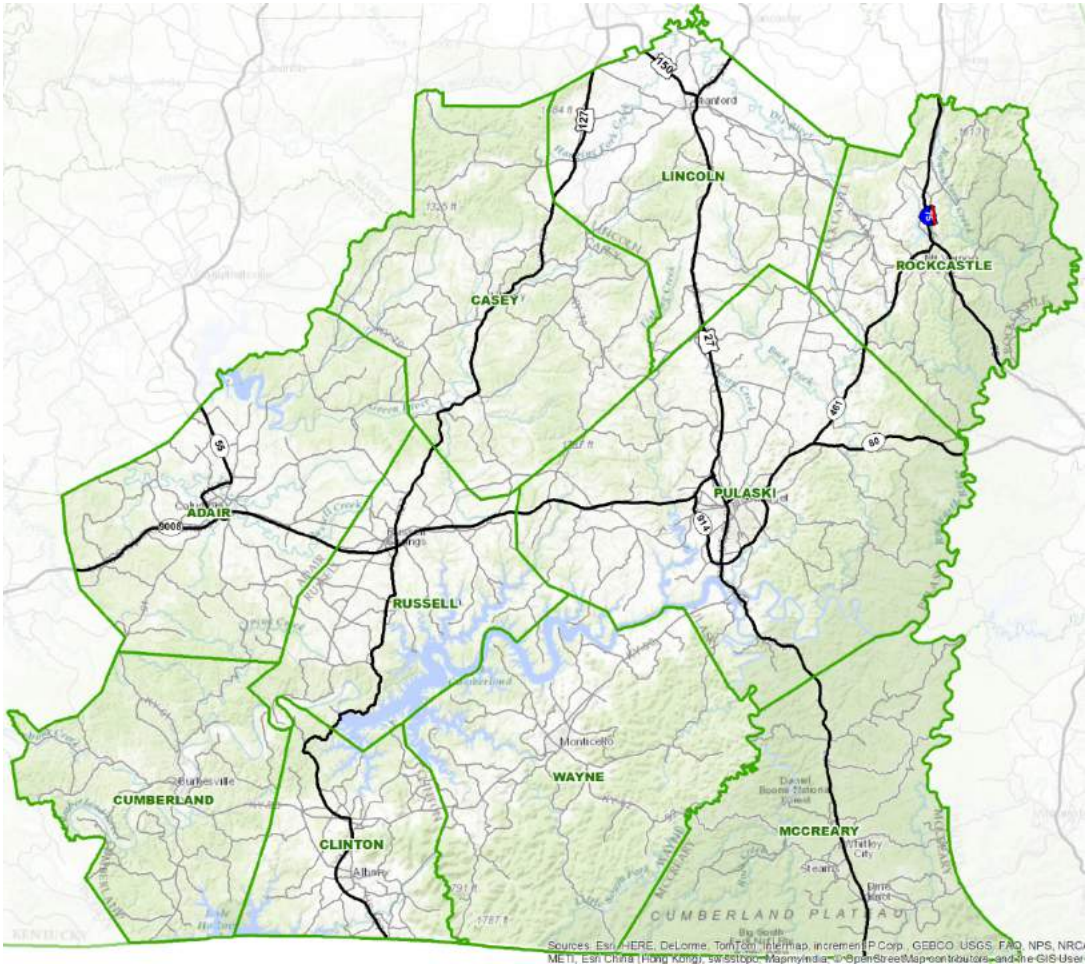


Figure 8-1. KYTC District 8 NHS

The NHS in District 8 is comprised of 449 miles of roadway, which is the fourth most of any district in the state (for divided highways, centerline miles are doubled in this total). District 8 NHS roadway segments include I-75 in Rockcastle County and Cumberland Parkway (LN-9008)

in Adair, Russell, and Pulaski Counties. US Highways that are a part of the NHS in the district include US-127 and US-27, which both run the extent of the district from north to south, and sections of US-150 and US-25. Additional NHS in District 8 include 34 bridges, 27 culverts, and 53 other structures.

8.2.Hazards

District 8 NHS assets, including highway segments, bridges, culverts, and other structures were assessed against the four primary hazards identified for this project: earthquake, flood, sinkhole, and landslide. Table 8-1 summarizes the relationship between these NHS assets and selected natural hazard indicators.

Table 8-1. Summary of District 8 NHS assets and natural hazard indicators

Asset Type	D8 Total	PGA ≥ 60 (Destructive)	PGA ≥ 30 and < 60 (Very Strong)	PGA ≥ 18 and < 30 (Strong)	In Flood Plain	Major Karst	Moderate Karst	High Landslide Susceptibility	Moderate Landslide Susceptibility
Total Road Miles	449	0	0	0	10	162	106	145	53
Interstate	48	0	0	0	1	14	0	41	0
Parkway	114	0	0	0	1	30	39	0	0
US Highway	201	0	0	0	7	56	57	45	53
KY Route	87	0	0	0	1	62	9	60	0
Local Road	0	0	0	0	0	0	0	0	0
Bridges	34	0	0	0	20	6	9	8	10
Culverts	27	0	0	0	17	4	9	6	9
Structures	53	0	0	0	0	21	17	16	1

8.2.1. Earthquake

The majority of District 8 does not lie in close proximity to any seismic zones and is not vulnerable to earthquakes. Southeastern parts of the District lie somewhat within proximity to the Eastern Tennessee Seismic Zone, though likely not close enough to experience any damage from an earthquake. Figure 8-2 shows where District 8 lies relative to USGS defined PGA zones. The majority of District 8, including most areas north and west of Somerset, lie in PGA Zone 10. Moving southeast from Somerset, the PGA zones gradually increase up to 20 in the southeastern tip of McCreary County. A PGA zone of less than 18 compares on the Modified Mercalli Scale to "Strong", which at this level, would not be expected to negatively impact or cause major damage to NHS assets in District 8. PGA zones in the District above 18 compares to "Very Strong", on the Modified Mercalli Scale where minor or moderate damage could occur from a seismic event. However, KYTC District 8 does not have any NHS assets located in PGA Zones above 18.

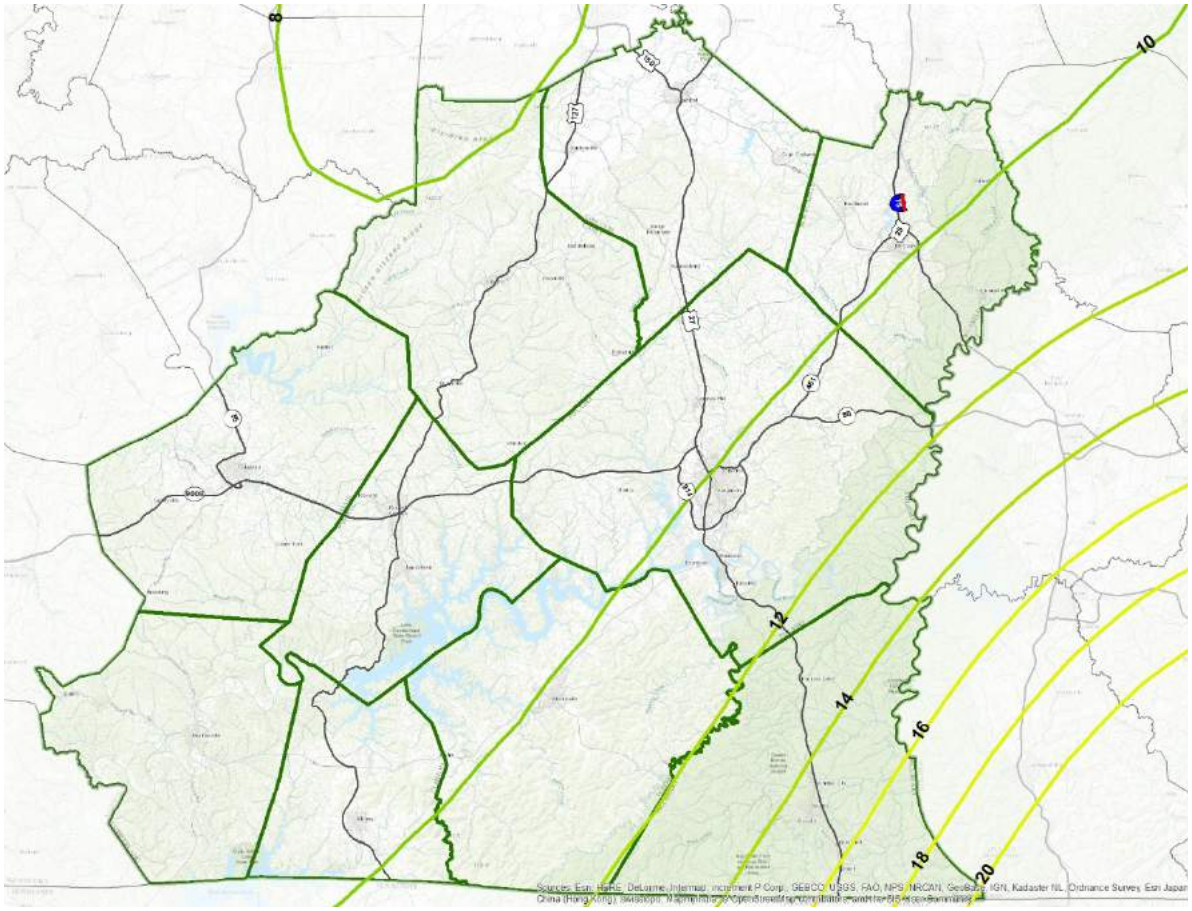


Figure 8-2. USGS PGA Zones in KYTC District 8

8.2.2. Flood

District 8 is drained by several different river systems. The majority and southern extent of the region is drained by the Cumberland River and Lake Cumberland. Lake Cumberland was formed after the construction of the Wolf Creek Dam in Russell County (completed in 1951) as a flood control reservoir for the river system. Most of Casey and Adair County to the west are drained by the Green River system. The northern most part of Casey County is drained by the Rolling Fork

system. The northern areas of Lincoln and Rockcastle counties drain into the Dix River as part of the Kentucky River system. The presence of Lake Cumberland minimizes the risk to flooding along the Cumberland River in this district. Parts of District 8 are also subject to sinkhole-related flooding. In all, District 8 has 10 miles of NHS roadway located in the 100-year floodplain. Other NHS assets located in the 100-year floodplain are 20 bridges and 17 culverts.

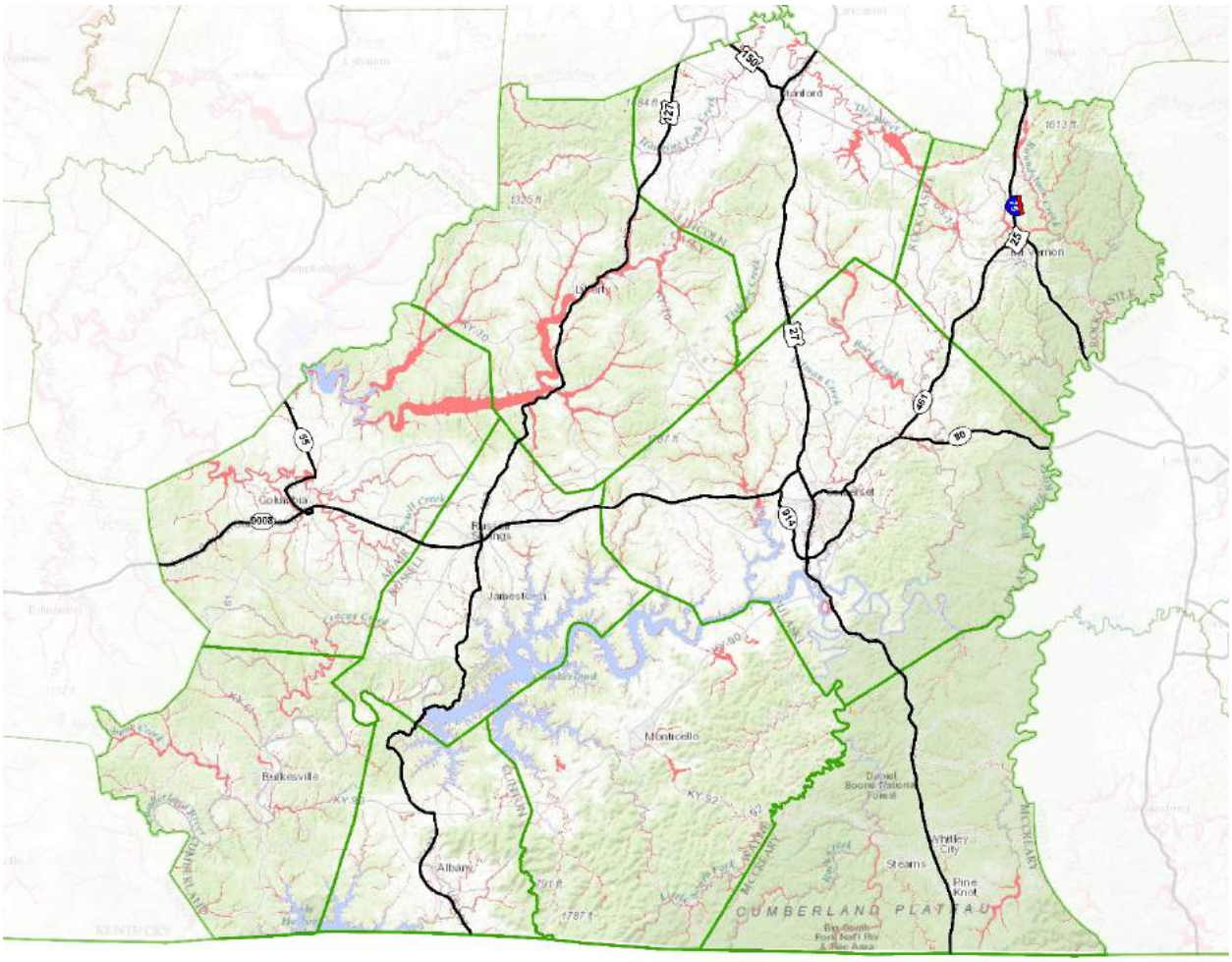


Figure 8-3. KYTC District 8; location of 100-year floodplain

From 1981 to 2015, counties in District 8 experienced extreme rainfall events (greater than 3" of rain in a single calendar day) on average every three to seven years, compared to the statewide average of an extreme rainfall event every four years. In general, the likelihood of experiencing such extreme rainfall events increases moving south and westward in the district.

8.2.3. Landslide

Figure 8-4 depicts landslide susceptibility and incidences in KYTC District 8. Areas to the east and south of the district along the Cumberland Plateau are most vulnerable to landslides. In all, District 8 has 145 miles of NHS highway located in areas identified by USGS has having high landslide incidence. Of these, 41 are interstate miles, 45 are US highway miles, and 60 are KY highway miles. Other NHS assets located in these areas of high landslide incidence include 8 bridges, 6 culverts, and 16 other NHS structures.

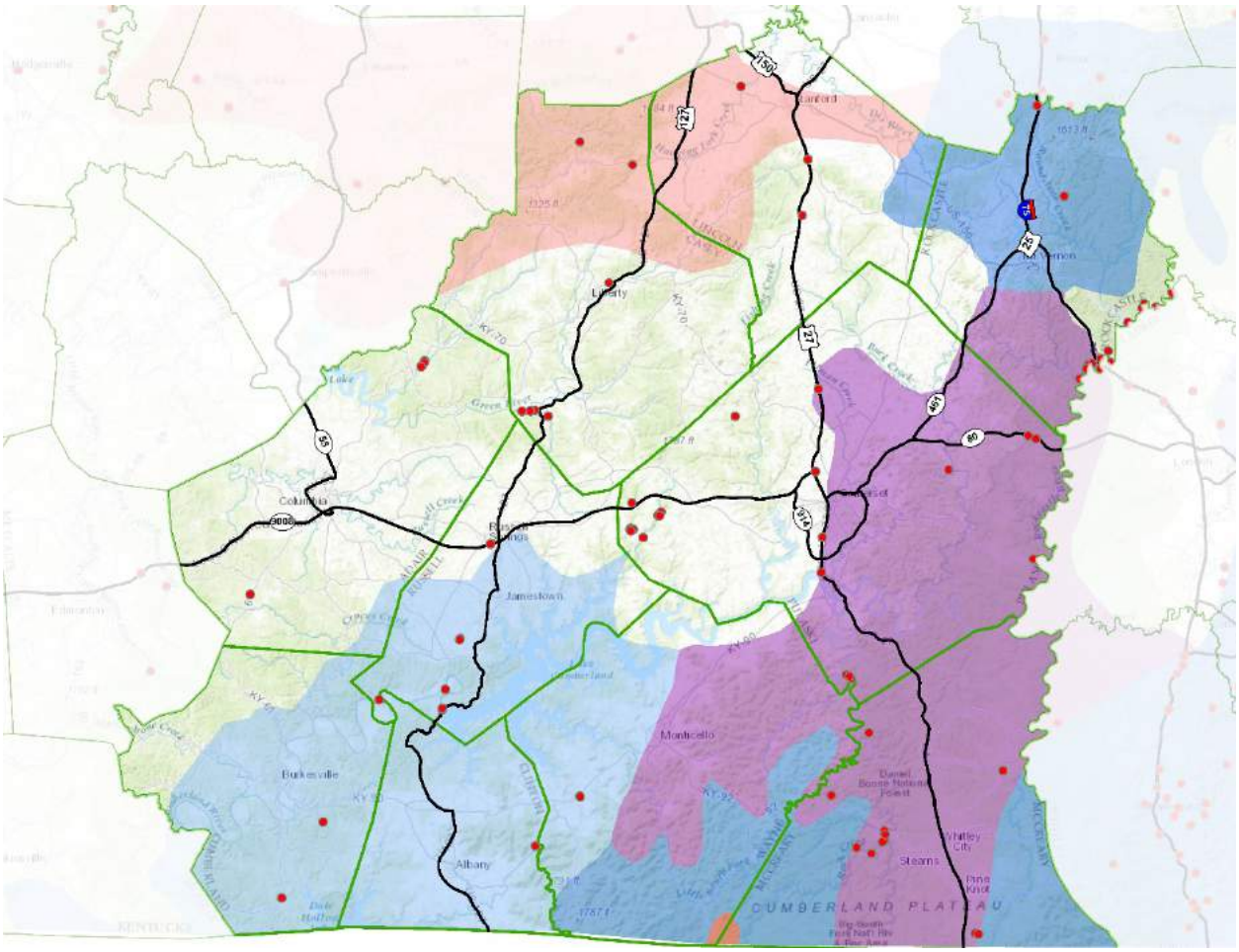


Figure 8-4. KYTC District 8 landslide incidence and susceptibility

Within the KGS landslide inventory database, landslides have been documented at the following locations along the NHS:

- Landslide US 27 MP 12.8; Lincoln County.
- Cut slope failures on US 27 at MP 6, MP 6.7, MP 9.2, MP 10.7; Lincoln County.
- Landslide above roadway I-75 at MP 72.5; Rockcastle County.
- Rock slope correction at the end of Wolf Creek Dam US 127 MP 1.8 to MP 2.4; Russell County.
- Landslide in Pulaski-Co., I-66 and US 27 (Somerset N. Bypass); Pulaski-County.
- Landslide US 27 MP 25 to MP 26; Pulaski-County.
- Sinkhole corrections on US 27 at MP 11.134; Pulaski-County.
- Landslide US-27 at MP 13.82; Pulaski-County.
- Cut slope landslide correction near contact with underlying Paragon Formation; Pulaski-County.

8.2.4. Karst

Sinkholes are a considerable hazard in District 8. As Figure 8-5 shows, sinkholes are common along a stretch just south of Lake Cumberland in Clinton County, northeastward through Wayne County, Pulaski-County, and into Rockcastle County. Sinkholes are also prevalent in central Adair County around Columbia.

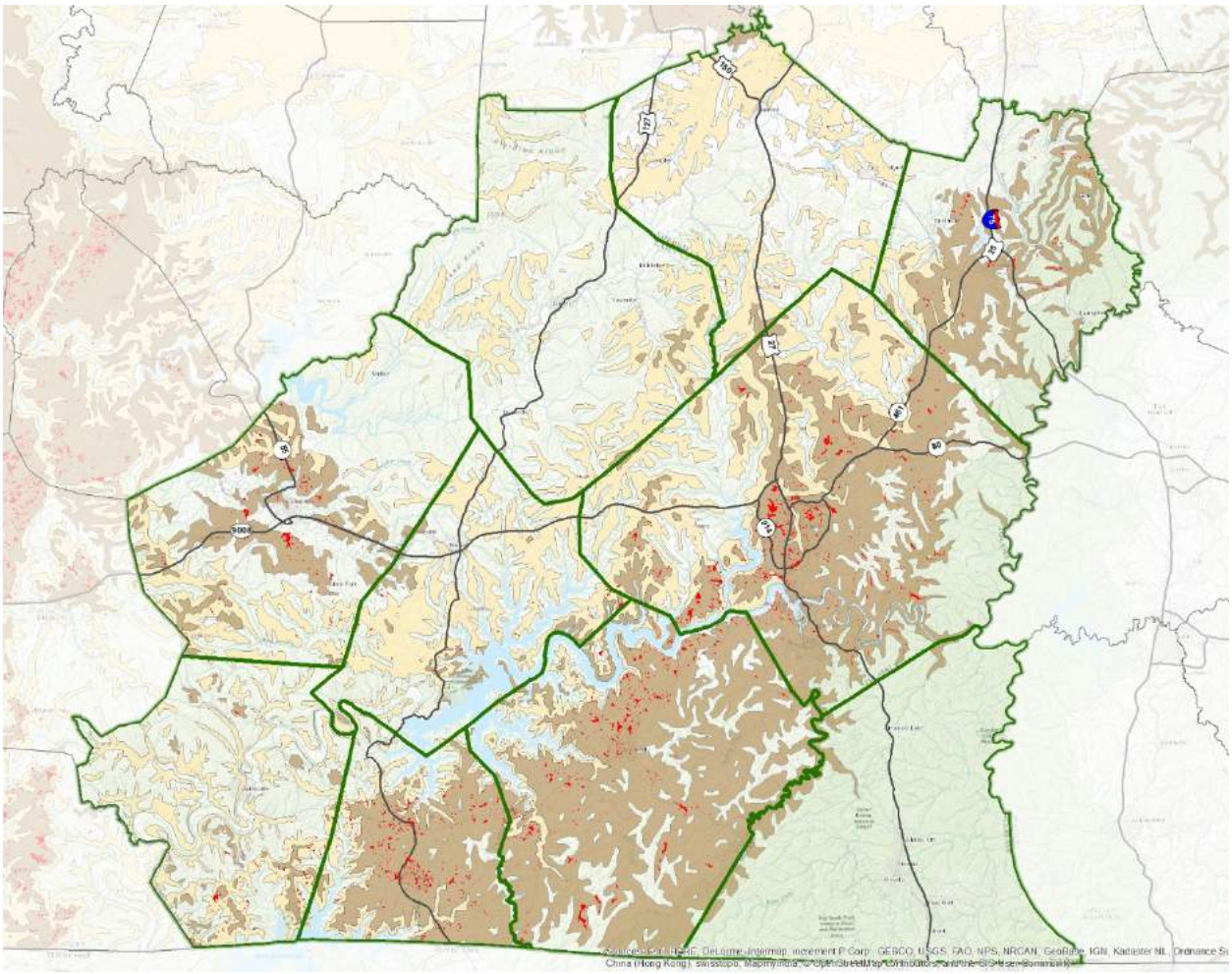


Figure 8-5. Karst potential and sinkholes in KYTC District 8

District 8 has 62 miles of NHS highway located in areas of high karst potential. These areas include: US 127 in Clinton County; US 27 in Pulaski County; KY 914 in Pulaski County; KY 80 in Pulaski County; KY 461 in Pulaski and Rockcastle Counties; portions of I-75 in Rockcastle County; the Cumberland Parkway in Adair County; and KY 55 in Adair County. Other NHS assets located in areas of major karst potential include 6 bridges, 4 culverts, and 21 other structures.

8.2.5. Other Meteorological Hazards

- Snow/Ice: All areas of District 8 average between 10” and 14” of annual snowfall, which is fairly typical of the state overall. Counties to the west of the district average the lowest annual snowfall totals, while counties to the north and east average the highest.
- Freeze/thaw: District 8 counties average between 80 and 105 annual freeze/thaw days. Areas to north in the Outer Bluegrass Region, including Lincoln average the fewest

freeze/thaw days, while areas to the south and east on the Cumberland Plateau, particularly McCreary County, experience the most.

- Extreme heat: District 8 counties average 1-4 days annually where the temperature exceeds 95 degrees Fahrenheit, compared to the statewide average of 4 such days annually. Areas to the west of the District, including Cumberland and Adair Counties, average the most days, while McCreary County in the southeast, averages the fewest.
- Drought/wildfire: Wildfires are somewhat more common in District 8 compared to the rest of the state, particularly moving south and east in the district. From 2002 to 2016, only fifty-seven wildfires were documented in the District. While most of these were small and their impacts minimal, several were significant. In 2012, a wildfire in McCreary County east of US 27 burned 579 acres. In 2014, a wildfire in southern McCreary County near the county line burned 565 acres. Both of these larger wildfires occurred in heavily wooded areas with minimal population. No NHS assets were impacted.
- Tornado: Compared to other districts in the state, District 8 has above average vulnerability to tornadoes. Tornado vulnerability is fairly even throughout the district, as all ten counties have experienced at least one F3 or above tornado since 1950. From 1950 to 2015, District 8 had 64 tornadoes overall, and 15 of intensity F3 and above tornadoes.

8.3.Workshop

The research team conducted a facilitated workshop in District 8 in March 2017. Twelve KYTC personnel attended the workshop. During this workshop, data was collected from participants through a series of facilitated events, including: 1) two keypad exercises where participants were asked to score the criticality of the roadway and the potential impacts of an extreme weather and/or natural hazard event, 2) a mapping exercise with a focused conversation to contextualize flooding events in the District, and 3) a consensus workshop where participants identified and discussed challenges to performing transportation system maintenance.

8.3.1. Polling Results

For the workshop, the NHS in District 8 was divided into 18 segments based upon road designation and county location. Workshop participants were provided with keypads and asked to evaluate each of the NHS segments for criticality and potential impacts from extreme weather and natural hazards. An overall vulnerability score for each segment was computed by multiplying together the criticality and impacts ratings. The vulnerability score, then, provided a metric for identifying highway segments that are both the most important and could potentially suffer the most damage from natural hazards. Table 8-2 displays the results of the workshop keypad assessments. The final column ranks each segment by the vulnerability score.

Table 8-2. District 8 workshop polling results showing criticality, impacts, and vulnerability

Segment ID	Segment Description	Criticality	Impacts	Vulnerability	Rank
1	US-127: Lincoln County	7.0	5.0	35.0	11
2	US-150: NW of US-27 in Lincoln County	7.3	4.3	30.8	14
3	US-27: Lincoln County	8.3	6.5	54.5	3
4	I-75: Rockcastle County	9.0	7.7	69.3	1
5	KY-461: Rockcastle County	7.6	4.6	35.2	10
6	US-127: Casey County	7.2	6.9	49.5	4
7	KY-55: Adair County north of Cumberland Parkway	6.6	3.5	23.2	16
8	Cumberland Parkway: Adair County	8.3	4.8	39.9	6
9	US-127: Russell County	7.6	7.9	60.0	2
10	Cumberland Parkway: Russell County	8.3	4.3	35.3	9
11	Cumberland Parkway: Pulaski-County	8.0	4.4	34.9	12
12	US-27: Pulaski-County north of Somerset	8.5	4.3	36.5	7
13	US-27: Pulaski-County, Somerset and south	8.4	5.6	46.7	5
14	KY-80: Pulaski-County, Somerset and east	7.8	4.7	36.5	8
15	KY-461: Pulaski-County	7.5	3.2	23.9	15
16	KY-914: Somerset	7.1	2.3	16.1	18
17	US-127: Clinton County	7.0	3.2	22.2	17
18	US-27: McCreary County	7.7	4.3	33.2	13

8.3.2. Map Exercise

Workshop participants were asked to review and mark up eight detailed maps of the NHS in District 8. The maps included NHS roadway segments and the associated bridges, culverts, and other structures; other state highways; streams, rivers, and other bodies of water; and the 100-year floodplain. Participants were asked to mark the maps and provide as much detail as possible for areas along the NHS that have 1) flooded in the past, 2) have been close to flooding in the past, and 3) are likely to flood during an extreme weather event. Table 8-3 displays the results of this exercise.

Table 8-3. KYTC District 8 NHS segments and flood

District	County	MP	Route	Hazard	Intersecting feature
8	Lincoln	3.45	US-150	Has flooded	none
8	Lincoln	20.8	US-27	Has flooded	@ Dix River
8	Rockcastle	68.1	I--75	Has flooded	@ Big Hurricane Branch
8	Casey	13.5	US-127	Has flooded	@ Green River
8	Pulaski	20.9	US-27	Has flooded	US127@1247
8	Pulaski	0	KY-914	Has flooded	between School Rd and US27

8.3.3. Workshop discussion

District 8 experiences problems with three of the four major natural hazards in this assessment: flooding, landslides, and sinkholes. District personnel identified several road segments in Pulaski-County, Wayne County, and Adair County that flood due to sinkhole-related drainage issues. These locations do not necessarily show up in the 100-year floodplain because the water is largely flowing underground. In cases of heavy rainfall, the sinks do not drain adequately causing water to back up on the surface, which can lead to high water and road closures. Several road segments that frequently flood were flagged due to lack of adequate transportation network resiliency. KY-90 in Wayne County floods frequently. Because there is no viable detour route, people in the area simply must wait for the water to recede.

A major flash flood event in April 2010 impacted multiple highways in District 8. Flooding on the Green River caused the closure of several bridges on KY-70 and US-127, nearly resulting in the town of Liberty being cutoff. The town of Brodhead was similarly nearly cutoff due to flooding on the Dix River and closures on US-150.

District 8 has two NHS segments built over the top of dams: US-127 in Russell County which is built over the Wolf Creek Dam on the Cumberland River, and I-75 in Rockcastle County. KYTC personnel highlighted these assets not necessarily because either is in imminent danger but rather because the potential impacts would be so severe. Dam failure in either case would be catastrophic to the area.

8.3.4. Roadways outside of the NHS that flood

District 8 personnel identified state roads throughout the district that have a recent history with flooding. In Adair County, roads in and around downtown Columbia along Russell Creek flood regularly, including KY-206 and KY-55X. In Pulaski-County, several roads experience karst-

related flooding: KY-196, KY-1642, and KY-39. US-27 in Pulaski-County north of Somerset was temporarily closed in 2016 due to flood water on the roadway. In Wayne County, KY-92 has a stretch of several hundred yards around MP 12 that floods. In Cumberland County, KY-100 had a stretch of pavement that was washed out due to flooding. Lincoln County has had problems with flooding on several roads, including KY-328, KY-1676, and KY-761.

8.3.5. Maintenance facilities flooding

The District 8 maintenance and facilities in Columbia (Adair County) have experienced minor flooding issues in the past. Though the facilities are not included in the 100-year floodplain, they are adjacent to the floodplain along Russell Creek. No other KYTC facilities in District 8 are known to have any flood problems.

8.3.6. Consensus workshop

For the consensus workshop, participants were asked to individually brainstorm about the following question; "What are the Greatest Challenges to Performing Maintenance in District 8?" Participants were asked to work in small groups to discuss and clarify their ideas. Ideas were then presented and group with all the participants. Table 8-4 provides the participants answers to the consensus workshop question.

Table 8-4. Results of KYTC District 8 consensus workshop

Identified Challenges to Conducting Maintenance Operations in District 8				
More Qualified Personnel	**Need a Realistic Budget**	**Equipment Availability**	**Cut Red Tape**	**Flexible Contract Procurement**
Personnel abilities	Lack of Money	Equipment Limitations	Policy Limitations -Environmental problems -R/W Purchases	Vendor issues (scheduling issues—we adjust to their schedule)
People	$$ -Need Budget Increase -Tracking use -Central Office: Management is too disengaged	Equipment Breakdown issues—need a quick fix	Eliminate Environmental Hoops -Permits	Contractor Availability -Number of crews per district -Guardrail, tree brush, drilling, paving
Traffic Maintenance (conflicting schedules Day/Night work)	Funding	Equipment	Eliminate Difficult approval Process	Contractor Requirements—Time and quantity
	Lack of Money	Specialized Equipment Availability (lack of)	Make the TC-10 Process easier (Funding)	Small Quantity prices for items (blacktop)
	Material Procurement -Spending Limits too low	Materials Availability -Tack oil -Bridge Repair -Specialized Equipment	Access R/W	In Place Small Qty Response time
	Materials Availability -Tack oil -Bridge Repair -Specialized Equipment	$5000 3 Bid Limitations	Bats	
			Consent Release	

8.4.Results

8.4.1. Identification of most at vulnerable assets

Table 8-5 lists District 8 NHS assets with a vulnerability score of 3.5 or greater for any of the four major hazards in this analysis (a full list of District 8 NHS assets and vulnerability scores is in Appendix 2). Flood, landslide, and sinkhole are all hazards that cause significant vulnerabilities in District 8. I-75 in Rockcastle County is scored as having the greatest vulnerability to both flooding and landslide, while US-27 in Pulaski-County is scored as having the greatest vulnerability to sinkholes. These results are similar to those from the workshop keypad scoring exercises, with a couple of notable differences. In the workshop, US-127 in Russell County received a higher vulnerability score due how the route passes over the Wolf Creek Dam. The Wolf Creek Dam, which holds back Lake Cumberland, has undergone considerable repairs from the US Army Corps of Engineers over the last decade, and workshop participants felt this was reflective of the vulnerability of the dam (and highway overtop).

Table 8-5. District 8 NHS assets with vulnerability score 3.5 or greater

District	County	Route	Vulnerability Score	Hazard
8	Pulaski	US 27	**3.54**	Flood
8	Casey	US 127	**3.63**	Flood
8	Rockcastle	I-75	**3.71**	Flood
8	Pulaski	US 27	**3.57**	Landslide
8	Rockcastle	I-75	**3.87**	Landslide
8	Pulaski	KY 914	**3.58**	Sinkhole
8	Pulaski	US 27	**3.72**	Sinkhole

8.4.2. Worst case scenario

Because of the importance of I-75 to the region, District 8 personnel identified any threat to this asset as the worst case scenario. I-75 in Rockcastle County has experienced some problems with flooding and landslides in the recent past, but not enough to pose a significant threat to the viability of the highway. The worst case scenario would be for I-75 and its designated detour route (US-25) to be closed at the same time due to landslide and/or flooding. The volume of traffic and freight on I-75 would be difficult for the transportation system to absorb if the US-25 detour route were unavailable.

9. KYTC District 9

9.1.District Overview

KYTC District 9 is located in northeastern Kentucky and includes the counties of Bath, Boyd, Carter, Elliott, Fleming, Greenup, Lewis, Mason, Nicholas, and Rowan. The area is largely rural, with Ashland, (population 21,038[21]) located along the Ohio River, being the largest city in the district. The Ohio River separating Kentucky from Ohio, forms the northern boundary of the district. The Big Sandy River separates Kentucky from West Virginia and forms the eastern boundary of the district. Other rivers in District 9 include the Licking River and the Little Sandy River. District 9 is bisected between the Outer Bluegrass geological region in the west, the Cumberland Plateau region in the east, and the Knobs region forming a line between the two.

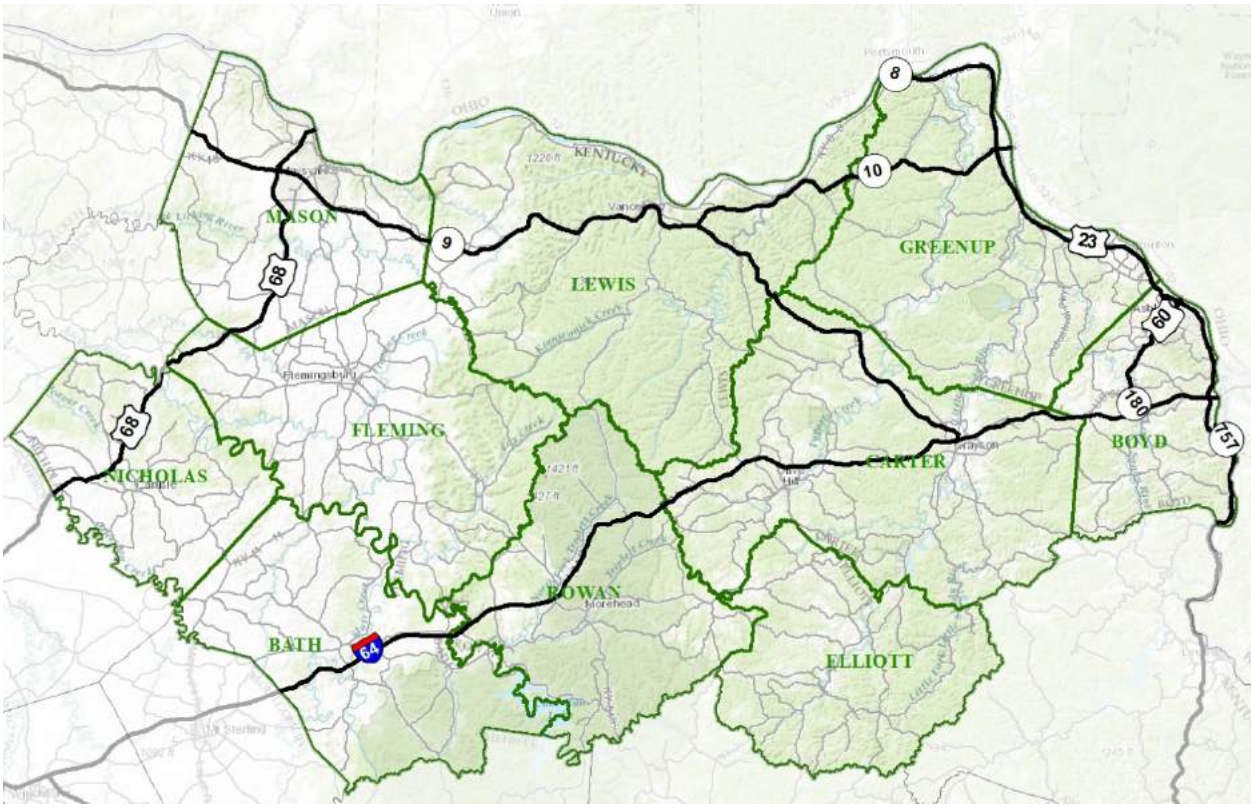


Figure 9-1.KYTC District 9 NHS

District 9 NHS assets include 430 miles of roadway, 55 bridges, 20 culverts, and 44 structures. District 9 NHS roadways include I-64 from Bath County to Boyd County, US-68 in Nicholas, Fleming and Mason County, US-23 in Greenup and Boyd counties, US-60 in Boyd County, and the AA Highway from Mason County to Boyd County. The D9 NHS includes three Ohio River bridges: the US-68 William H. Harsha Bridge in Maysville, the KY-8 Carl Perkins Bridge in Greenup County, and the KY-10 Jesse Stuart Bridge over the Greenup Locks and Dam. Other critical bridges include the I-64 Perry-Gentry Bridge over the Big Sandy River and the I-64 bridge over the Licking River.

[21] U.S. Census Bureau, Population Division.

9.2.Hazards

District 9 NHS assets, including highway segments, bridges, culverts, and other structures were assessed against the four primary hazards identified for this project: earthquake, flood, sinkhole, and landslide. Table 9-1 summarizes the NHS assets and their relationship to natural hazard indicators in the district.

Table 9-1. Summary of District 9 NHS assets and natural hazard indicators

Asset Type	D9 Total	PGA ≥ 60 (Destructive)	PGA ≥ 30 and < 60 (Very Strong)	PGA ≥ 18 and < 30 (Strong)	In Flood Plain	Major Karst	Moderate Karst	High Landslide Susceptibility	Moderate Landslide Susceptibility
Total Road Miles	430	0	0	0	19	28	74	182	102
Interstate	168	0	0	0	9	18	14	104	13
Parkway	0	0	0	0	0	0	0	0	0
US	156	0	0	0	6	9	23	53	48
KY	107	0	0	0	4	0	36	24	41
Local Road	0	0	0	0	0	0	0	0	0
Bridges	55	0	0	0	27	4	6	26	16
Culverts	20	0	0	0	14	4	5	7	5
Structures	44	0	0	0	2	9	7	28	7

9.2.1. Earthquake

Earthquake is not a significant hazard in District 9. Figure 9-2 shows where District 9 lies relative to USGS defined PGA zones. The majority of District 9 lies in PGA Zone 8, which compares on the Modified Mercalli Scale to "Slightly Strong" and seismic activity at this level would not be expected to negatively impact or cause major damage to NHS assets in District 9.

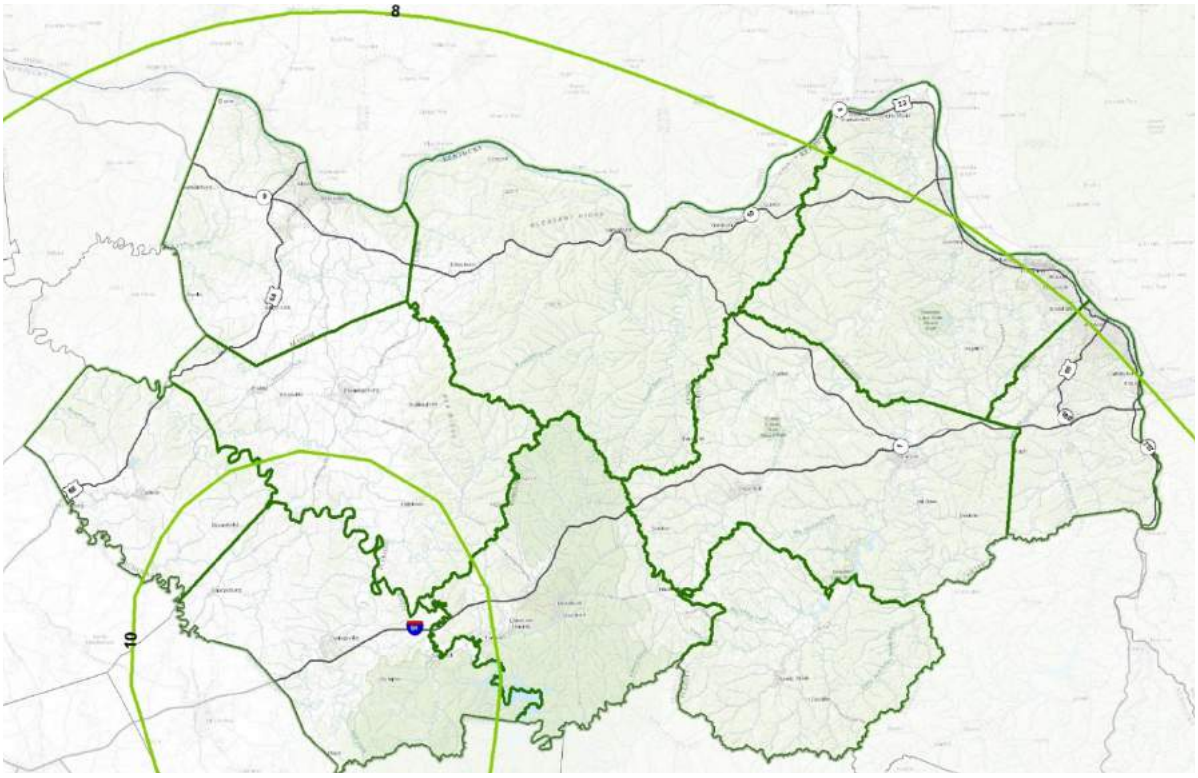


Figure 9-2. PGA Zones in KYTC District 9

9.2.2. Flood

The eastern areas of District 9 drain into the Ohio River, while the western areas of the district drain westward into the Licking River system. In all, District 9 NHS assets that are located in the 100-year floodplain include 23 miles of roadway, 33 bridges, 16 culverts, and one other structure.

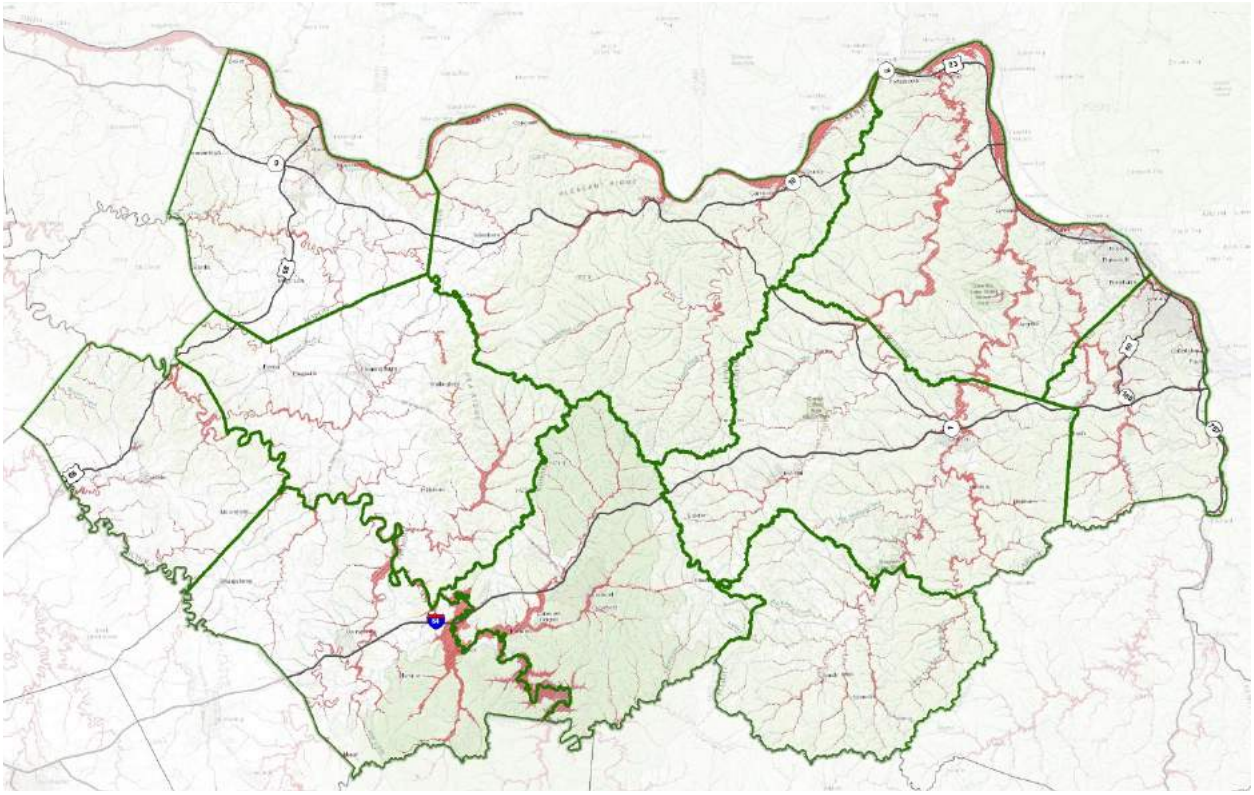


Figure 9-3. KYTC District 9; location of 100-year floodplain

From 1981 to 2015, counties in District 9 experienced extreme rainfall events (greater than 3" of rain in a single calendar day) on average every five to ten years, compared to the statewide average of an extreme rainfall event every four years. Overall, areas in the western part of the district experienced such extreme rainfall events nearly twice as often as those in the eastern areas of the district.

9.2.3. Landslide

Figure 9-4 identifies USGS landslide susceptibility and incidences of documented slides in District 9. As illustrated by this figure, areas in the eastern and southern part of the district are the most vulnerable to landslides. In total, NHS assets in District 9 that are located in high landslide areas include: 182 miles of roadway, 7 culverts, and 28 other structures.

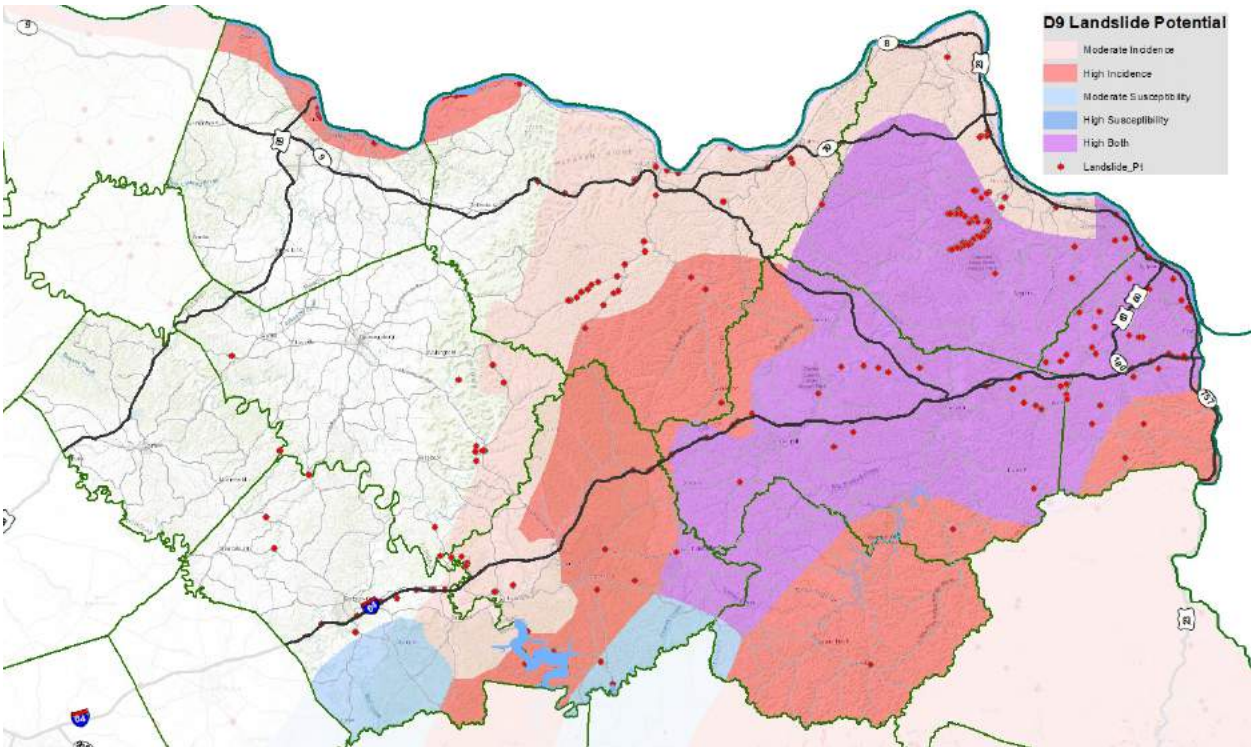


Figure 9-4. Landslide incidence and susceptibility in KYTC District 9

As documented by the KGS landslide inventory database, landslides have been documented at the following locations along the NHS:

- Entire slope sliding with pockets slumping along KY 9; Lewis County.
- Rockfall US 23, large boulders on both lanes of US 23, road closed; Greenup County.
- Construction landslide at intersection of US 23 and KY 207 Ramp B; Greenup County.
- Landslide US 23 at MP 12.3 and MP 12.4; Greenup County.
- Rockfall US 32 at MP 20.9, large blocks in roadway, one lane closure; Boyd County.
- Embankment landslide correction on I-64 WB at MP 121 to MP 122; Bath County.
- Landslide Correction on I-64 at MP 123.33 EB, MP 124.07 WB, MP 124.29 WB, MP 124.56 WB, MP 125.36 WB, MP 126.84 WB, MP 126.5 EB, MP 127.74 EB; Bath County.
- Landslide on I-64 from MP 123.0 to 129.0 at KY 211 Bridge over I-64; Bath County.
- Embankment landslide on I-64 WB at MP 118.8; Bath County.
- Embankment Slope Failure Corrections on I-64 WBL MPs 120.0 and 126.0; Bath County.
- Landslide I-64 MP 123.6, MP 123.3; Bath County.
- Landslide on I-64 near MP 148; Rowan County.
- Embankment landslide correction on I-64 EB from MP 147.5 to 147.87; Rowan County.
- Rockfall I-64 at MP 146.6; Rowan County.
- Landslide Correction on I-64 at MP 149.8; Carter County.
- Embankment slide I-64 MP 152.7; Carter County.
- Rockfall I-64 MP 174.7; Carter County.
- Landslide I-64 MP 189.2; Boyd County.
- Landslide I-64 MP 187.6 to MP 187.7; Boyd County.

- Embankment Failure I-64 at MP 190.9 to MP 191.1; Boyd County.
- Landslide I-64 MP 186.1; Boyd County.

9.2.4. Karst

Karst topography does not pose a significant hazard to NHS assets in District 9. However, some areas in Carter County, Rowan County, and Nicholas County are located in high karst potential areas. Areas of moderate karst potential in the district are located in Mason County, Fleming County, Lewis County, and Bath County. However, KGS has documented few sinkholes in these areas, and district personnel did not report significant problems or impacts to transportation assets from sinkhole subsidence. In District 9, there are 28 miles of NHS highway located in areas of high karst potential, including I-64 in Carter County and US 68 in Nicholas County. Other NHS assets located in areas of major karst potential include 4 bridges, 4 culverts, and 9 other structures.

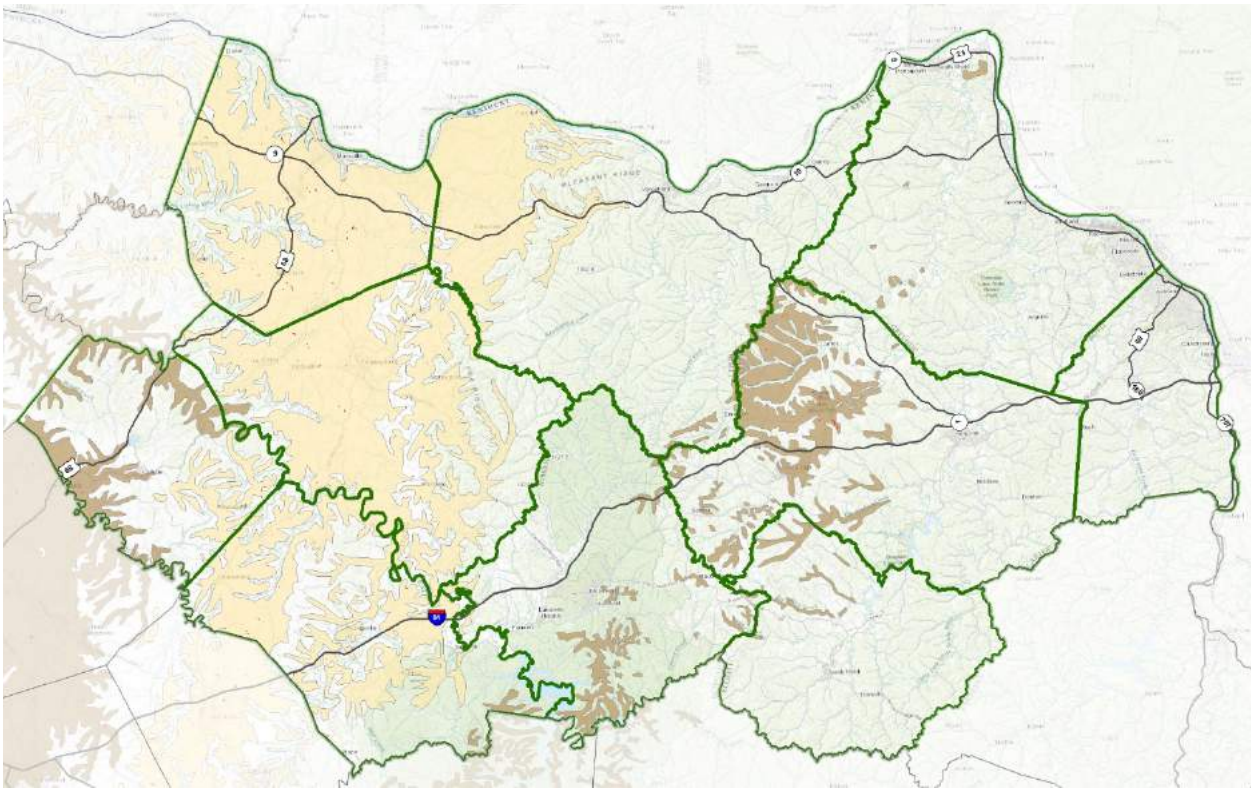


Figure 9-5. Karst potential and sinkholes in KYTC District 9

9.2.5. Other Meteorological Hazards

- Snow/Ice: District 9 averages between 11" and 14" of annual snowfall, which is fairly typical of the state overall.
- Freeze/thaw: District 9 counties average between 84 and 105 annual freeze/thaw days. Eastern areas of the district experience more freeze/thaw days than anywhere else in the state, with Carter County averaging 105 freeze/thaw days annually from 1981-2015.
- Extreme heat: District 9 counties average around 2.5 days annually where the temperature exceeds 95 degrees Fahrenheit, compared to the statewide average of 4 such days annually. This average is fairly consistent across all counties in the district.

- Drought/wildfire: Wildfires are somewhat more common in District 9 compared to the rest of the state, particularly in the eastern half of the district. From 2002 to 2016, thirty-two wildfires were documented in the District. While most of these were small and their impacts minimal, one was significant. In 2010, a wildfire in Rowan County 6.5 miles southwest of Morehead burned 368 acres. This fire occurred in a heavily wooded area with minimal population. No NHS assets were impacted.
- Tornado: Compared to other districts in the state, District 9 has lower than average vulnerability to tornadoes. From 1950 to 2015, District 9 had 24 tornadoes overall, and 3 tornadoes of intensity F3 and above.

9.3.Workshop

The research team conducted a facilitated workshop in District 9 in June 2017. Ten KYTC personnel attended the workshop. During the workshop, data was collected from participants through a series of facilitated events, including: 1) two keypad exercises where participants were asked to score the criticality of the roadway and the potential impacts of an extreme weather and/or natural hazard event, 2) a mapping exercise with a focused conversation to contextualize flooding events in the District, and 3) a consensus workshop where participants identified and discussed challenges to performing transportation system maintenance.

9.3.1. Polling Results

For workshop exercises, mapping was provided that divided the NHS into 22 functional roadway segments. Some of these segments included multiple routes, though most segments were contained to a single county. Participants were provided with keypads and asked to evaluate each of the NHS segments for criticality and potential impacts from extreme weather and natural hazards. An overall vulnerability score for each segment was computed by multiplying together the criticality and impacts ratings. The vulnerability score, then, provided a metric for identifying highway segments that are both the most important and could potentially suffer the most damage from natural hazards. Table 9-2 displays the results of the workshop keypad assessments. The final column ranks each segment by the vulnerability score.

Table 9-2. District 9 workshop polling results showing criticality, impacts, and vulnerability

Segment ID	Segment Description	Criticality	Impacts	Vulnerability	Rank
1	US 68: Nicholas County	5.8	4.0	23.1	20
2	US 68: Fleming County	5.6	3.7	20.5	21
3	US 68: Mason County south of AA Hwy	6.0	3.9	23.4	19
4	US 68: William H. Harsha Bridge and approach	7.5	6.5	48.8	8
5	KY 9: Mason County	7.1	5.0	35.5	13
6	KY 9: Lewis County	6.6	4.7	31.0	15
7	KY 10: Lewis County	6.2	4.6	28.2	16
8	KY 10: Greenup County	6.3	4.2	26.5	18
9	KY 10: Jesse Stuart Bridge at Greenup Locks & Dam	7.5	5.9	44.2	10
10	KY 8: Carl Perkins Bridge and approach	8.0	6.1	48.9	7
11	US 23: Greenup County north of KY 10	7.0	4.9	34.2	14
12	US 23: Greenup County south of KY 10	7.5	5.5	41.3	12
13	I-64: Bath County	8.6	5.8	49.7	6
14	I-64: Rowan County	8.7	6.4	55.7	4
15	I-64: Carter County	8.3	6.3	52.6	5
16	KY 9: Carter County	6.5	4.3	28.0	17
17	I-64: Boyd County	8.6	6.8	58.5	3
18	I-64: Bridge over Big Sandy and approach	8.9	7.9	70.3	1
19	US 60/KY 180: Boyd County north of I-64	7.6	5.6	42.2	11
20	US 60/US 23S: Ashland & Williamson/Willis Bridges	8.6	7.3	62.8	2
21	US 23: Boyd County	7.7	6.2	47.9	9
22	KY 757: Riverport and industrial access	5.7	2.0	11.4	22

9.3.2. Map Exercise

Workshop participants were asked to review and mark up eight detailed maps of the NHS in District 9. The maps included NHS roadway segments and the associated bridges, culverts, and other structures; other state highways; streams, rivers, and other bodies of water; and the 100-year floodplain. Participants were asked to mark the maps and provide as much detail as possible for areas along the NHS that have: 1) flooded in the past, 2) have been close to flooding in the past, and 3) are likely to flood during an extreme weather event. Table 9-3 displays the results of this exercise.

Table 9-3. District 9 NHS segments and flood

District	County	MP	Route	Hazard	Intersecting feature
9	Lewis	16.1	KY-9	Has flooded	Salt Lick Creek
9	Lewis	18.2	KY-9	Has flooded	Salt Lick Creek
9	Lewis	19.8	KY-9	Has flooded	Little Branch
9	Lewis	24.25	KY-9	Has flooded	Bethel Creek Trib
9	Lewis	28.38	KY-9	Has flooded	@ KY-57
9	Lewis	29.5	KY-9	Has flooded	Drainage?
9	Lewis	0	KY-10	Has nearly flooded	Kinniconick Creek
9	Greenup	28.5	US-23	Has flooded	Maybe KY 8
9	Greenup	4.5	US-23	Has flooded	@ Pond Run Road
9	Greenup	0.2	KY-693	Has flooded	Boyd County border
9	Bath	120.05	I--64	Has nearly flooded	Slate Creek
9	Rowan	146.5	I--64	Has flooded	MP 146 to 147
9	Rowan	144.5	I--64	Has flooded	MP not exact-within 1 mi
9	Boyd	5.8	US-60	Has flooded	E Fork Little Sandy Tributary
9	Boyd	1.7	KY-180	Has flooded	E Fork Little Sandy River

9.3.3. Workshop discussion

KYTC personnel identified multiple roadways in District 9 that have been impacted significantly by flood. KY-9 at Cabin Creek in Lewis County has come very close to flooding. KYTC personnel have had to pump out blocked culverts to address water backing up toward the roadway. US-23 in Greenup County near Raceland has had problems with flooding though recent KYTC projects have tried to fix the problem. US-23 near the Greenup/Boyd County line also has issues with flooding as many of the surrounding roads flood frequently, causing problems to the whole transportation system.

Bath County and Rowan County have considerable problems with flooding, particularly along the Licking River and tributaries. The town of Salt Lick is particularly vulnerable; one KYTC personnel remarked that it is only a matter of time before catastrophic flooding impacts that community. In 2010, heavy precipitation led to flooding throughout the area, cutting off Morehead from the interstate due to water over US-60. An I-64 ramp to Morehead was also submerged during this event.

9.3.4. Roadways outside of the NHS that flood

In Fleming County, KY-57 is undergoing a bridge project to address frequent flooding. In Carter County, US-60 experienced major flooding in 2015 that not only affected the roadway but also impacted houses and cars due to flash flooding. In Boyd County, US-60 was impacted by flooding in 2012, as water and debris caused the roadway to be closed for several days.

9.3.5. Maintenance facilities flooding

The Rowan County maintenance barn was affected by flooding in 2010. Though it doesn't flood frequently, access to the facility is often blocked by flood water. The Bath County maintenance facility is reported to flood frequently.

9.3.6. Consensus workshop

For the consensus workshop, participants were asked to individually brainstorm about the following question; "What are the Greatest Challenges to Performing Maintenance in District 9?" Participants were asked to work in small groups to discuss and clarify their ideas. Ideas were then presented and group with all the participants. Table 9-4 provides the participants answers to the consensus workshop question.

Table 9-4. Results of District 9 consensus workshop

Identified Challenges to Conducting Maintenance Operations in District 9						
Traffic Concerns and Issues	**Lack of Equipment**	**Lack of Funding**	**Red Tape and Bureaucracy**	**Staffing and Personnel**	**District Diversity**	**Productivity Issues**
Traffic	Equipment	Lack of Funding	Unnecessary Bureaucracy: Policy, Resource agencies, rules in general	Manpower	Geographical Challenges and Changes	Fighting Fires vs. Routine Maintenance
Traffic Control and Issues	Better/More Equipment	Funding Source/Intent Allocation	Time	Limited Personnel	Topography	Employee Morale
Traffic Control and Issues	Lack of Equipment	Funding	Defined Work Hours--Need Flexibility 4-10 hours days or 5-10 hour days	Lack of Personnel	Defined County Lines	Customer Expectations
Traffic, Distracted Drivers		Limited Funding (Budget)	Bats and other environmental concerns	Personnel/ Equipment		
		Money	Changes in Project Prioritization			

9.4.Results

9.4.1. Identification of most at vulnerable assets

Table 9-5 lists District 9 NHS assets with a vulnerability score of 3.5 or greater for any of the four major hazards in this analysis (a full list of District 9 NHS assets and vulnerability scores is in Appendix 2). Landslide is the one hazard that causes the greatest vulnerability in District 9, with I-64 in Boyd County having the highest overall vulnerability score. The results of this analysis closely mirror those from the keypad scoring at the District 9 workshop, where I-64 segments in Boyd County, Rowan County, and Carter County were all rated among the most vulnerable. US-23 in Greenup County was also similarly scored as having high vulnerability to landslide in both scoring methods.

Table 9-5. District 9 NHS assets with vulnerability score 3.*5 or greater*

District	County	Route	Vulnerability Score	Hazard
9	Rowan	I-64	**3.63**	Landslide
9	Greenup	US 23	**3.70**	Landslide
9	Carter	I-64	**3.72**	Landslide
9	Boyd	I-64	**3.87**	Landslide

9.4.2. Worst Case Scenario

Any closure of I-64 would constitute the worst case scenario for this district. The I-64 bridge over the Big Sandy River is one spot that is vulnerable. Several stretches of I-64 in the district have been impacted by landslides and rockfalls. Any type of major landslide that damaged I-64 for a prolonged period of time would have considerable mobility, safety, and economic implications for the area.

10. District 10

10.1. District Overview

KYTC District 10 is located in eastern Kentucky and encompasses the counties of Breathitt, Estill, Lee, Magoffin, Menifee, Morgan, Owsley, Perry, Powell, and Wolfe. District 10 is a largely mountainous area of Kentucky. The largest city in the district is Hazard with a population of 5,300[22]. Rivers in District 10 include the Kentucky River, Red River, and Licking River. District 10 is in the Cumberland Plateau physiographic region, which encompasses the Appalachian Mountains from Pennsylvania to Alabama. The Cumberland Plateau region is characterized by forested hills and highly dissected by V-shaped valleys.

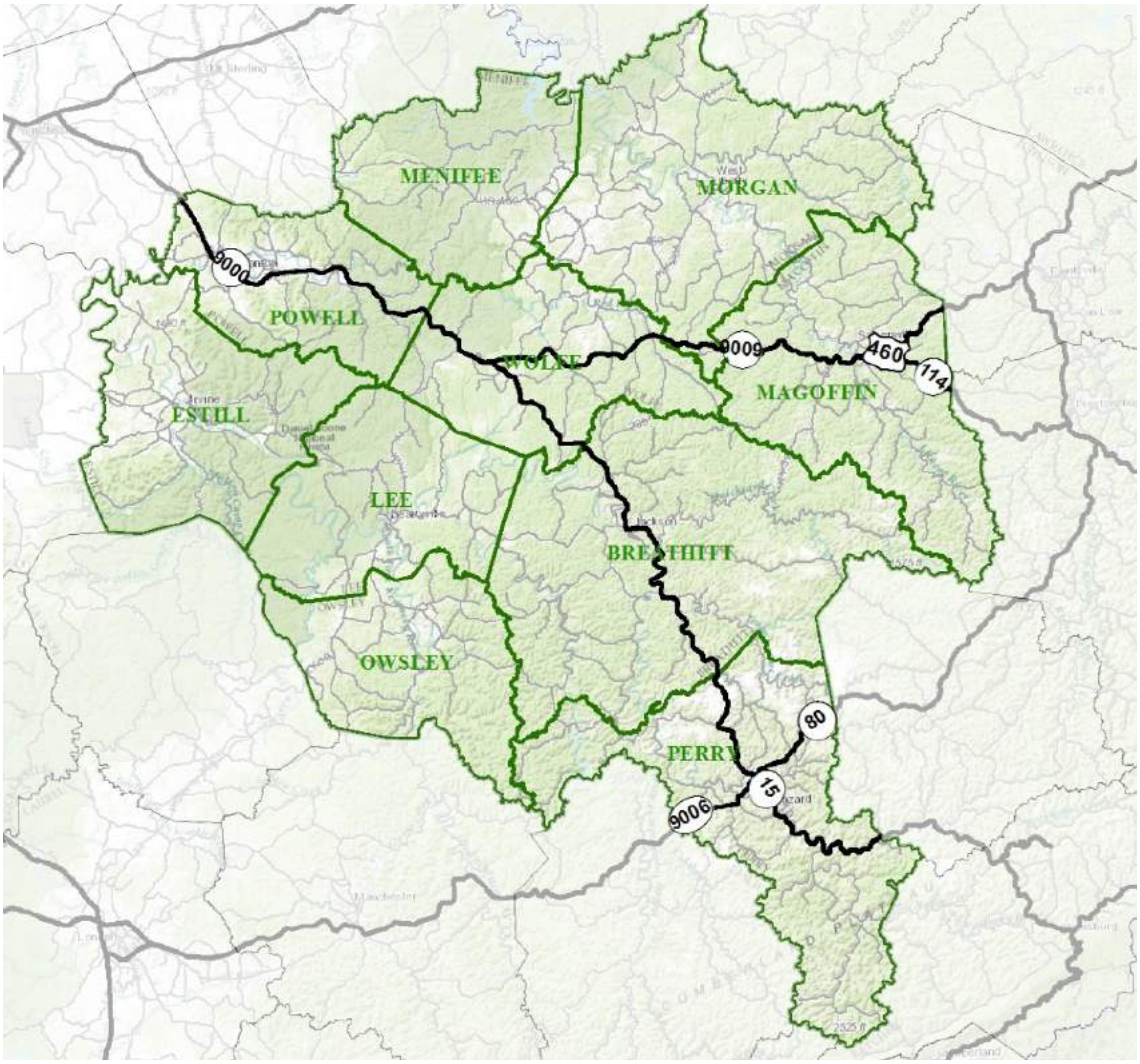


Figure 10-1.KYTC District 10 NHS

The NHS in District 10 is comprised of 225 centerline miles of roadway, which is the fewest of any district in the state (for divided highways, centerline miles are doubled in this total). District 10 NHS includes the Mountain Parkway (KY-9000/KY-9009) in Powell, Wolfe, Morgan, and

[22] U.S. Census Bureau, Population Division.

Magoffin counties, the Hal Rogers Parkway (HR-9006) in Perry County, and KY-15 in Wolfe, Breathitt, and Perry counties. The NHS also includes smaller segments of US-460 in Magoffin County, KY-114 in Magoffin County, and KY-80 in Perry County. Additional NHS assets in the district include 59 bridges, 21 culverts, and 42 other structures.

10.2. Hazards

District 10 NHS assets, including highway segments, bridges, culverts, and other structures were assessed against the four primary hazards identified for this project: earthquake, flood, sinkhole, and landslide. Table 10-1 summarizes the relationship between these NHS assets and selected natural hazard indicators.

Table 10-1. Summary of KYTC District 10 NHS assets and natural hazard indicators

Asset Type	D10 Total	PGA ≥ 60 (Destructive)	PGA ≥ 30 and < 60 (Very Strong)	PGA ≥ 18 and < 30 (Strong)	In Flood Plain	Major Karst	Moderate Karst	High Landslide Susceptibility	Moderate Landslide Susceptibility
Total Road Miles	225	0	0	0	23	2	0	174	17
Interstate	0	0	0	0	0	0	0	0	0
Parkway	118	0	0	0	0	0	0	11	0
US	8	0	0	0	0	0	0	8	0
KY	99	0	0	0	23	2	0	155	17
Local Road	0	0	0	0	0	0	0	0	0
Bridges	59	0	0	0	33	0	0	46	11
Culverts	21	0	0	0	16	0	0	13	4
Structures	42	0	0	0	1	0	0	25	14

10.2.1. Earthquake

The majority of District 10 does not lie within close proximity to any seismic zones and is not vulnerable to earthquakes. Southern parts of the District lie somewhat within proximity to the Eastern Tennessee Seismic Zone, though likely not close enough to experience any damage from an earthquake. Figure 10-2 shows where District 10 lies relative to USGS defined PGA zones. The majority of District 10 lies in PGA Zones 8 and 10. The northern half of Perry County is in PGA Zone 12, the central area in PGA Zone 14, and the southern tip of the county is in PGA Zone 16. A PGA zone of less than 18 compares on the Modified Mercalli-Scale to "Strong", which is described as "Sleepers awake; church bells ring." Seismic activity at this level would not be expected to negatively impact NHS assets in District 10.

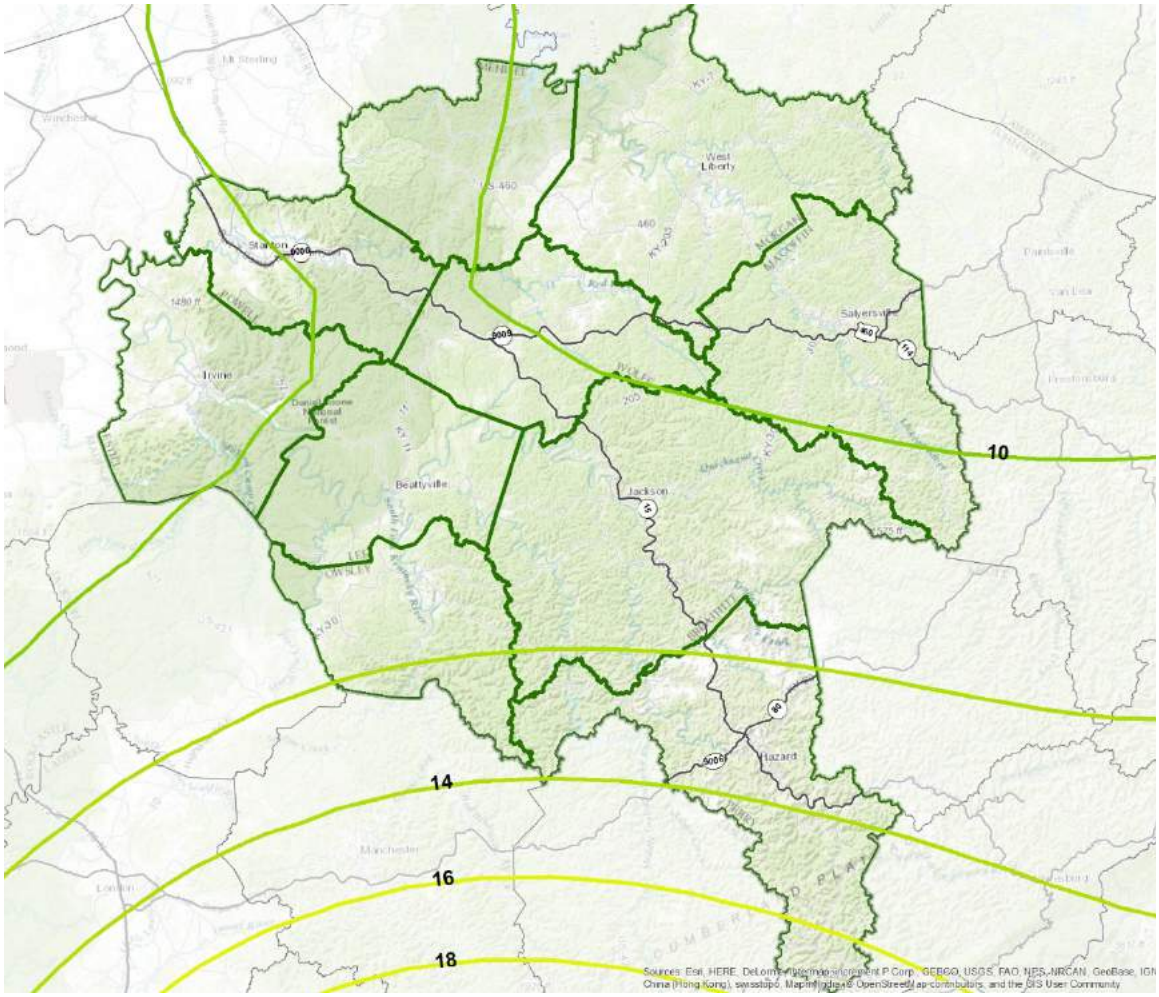


Figure 10-2. USGS PGA Zones in KYTC District 10

10.2.2. Flood

District 10 is drained by two river systems. The majority of the region is drained by the Kentucky River system, with streams in this system flowing west and northward. Magoffin County, Morgan County and eastern Menifee County are drained by the Licking River system, with streams in this system flowing northward. In all, District 10 has 23 miles of NHS roadway located in the 100-year

floodplain. Other NHS assets located in the 100-year floodplain are 33 bridges, 16 culverts, and one other structure.

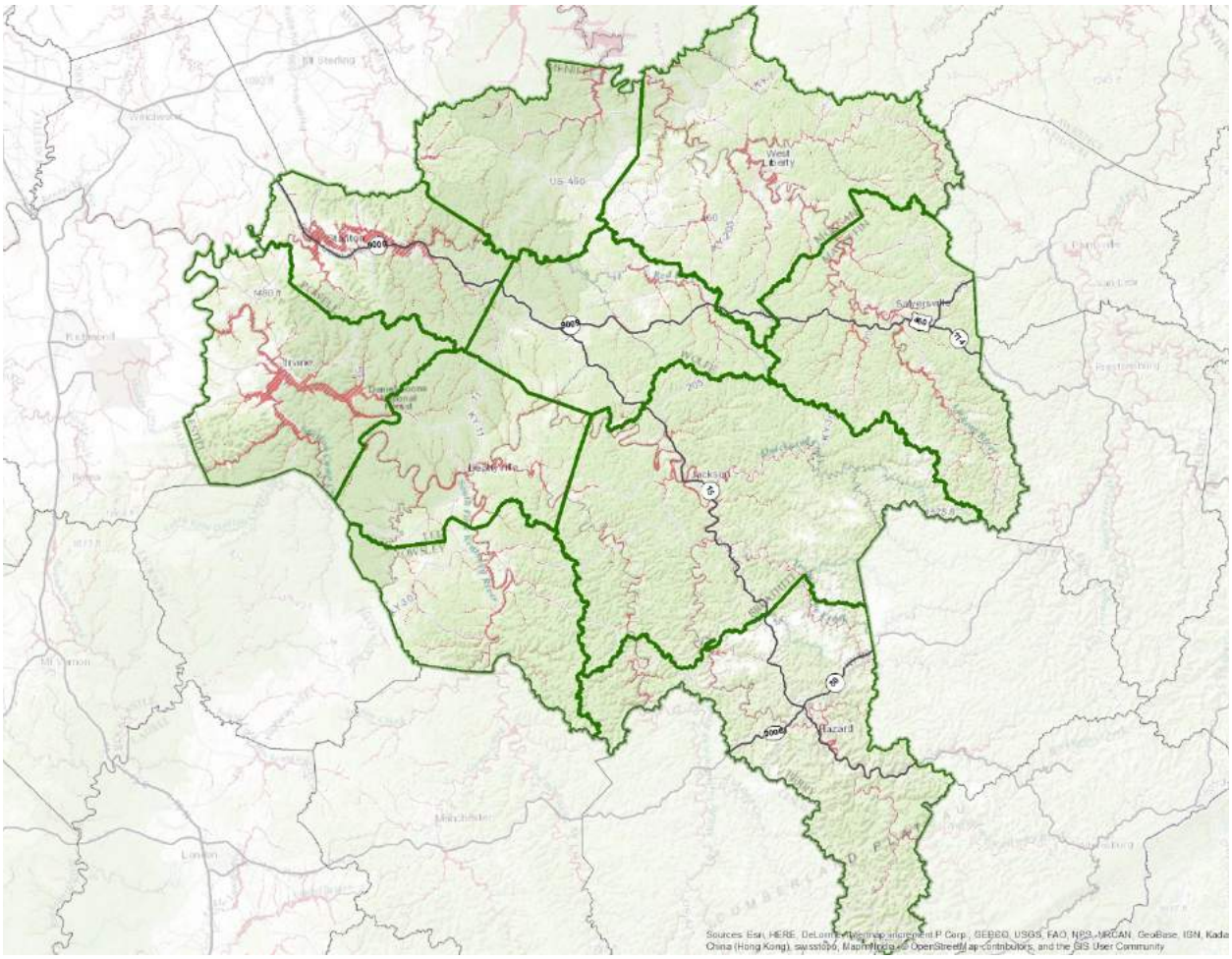


Figure 10-3. KYTC District 10; location of 100-year floodplain

From 1981 to 2015, counties in District 10 experienced extreme rainfall events (greater than 3" of rain in a single calendar day) on average every five to fifteen years, compared to the statewide average of an extreme rainfall event every four years. Western areas of the district, including Menifee, Powell, Estill, Lee, and Owsley County, experienced such rainfalls closer to every five years, while the remaining counties in the eastern part of the district all were closer to every fifteen years.

10.2.3. Landslide

Landslides are a major hazard in District 10. Figure 10-4 is a map of landslide susceptibility and documented incidences in District 10. Landslides have been documented in every county in the district, with counties to the south, including Perry County, Breathitt County, and Magoffin, having the highest totals.

In all, District 10 has 174 miles of NHS highway located in high landslide susceptibility areas identified by USGS. Of these, 11 are parkway miles, 8 are US highway miles, and 155 are KY

highway miles. Additional NHS district assets located in areas of high landslide vulnerability include 46 bridges, 13 culverts, and 25 other NHS structures.

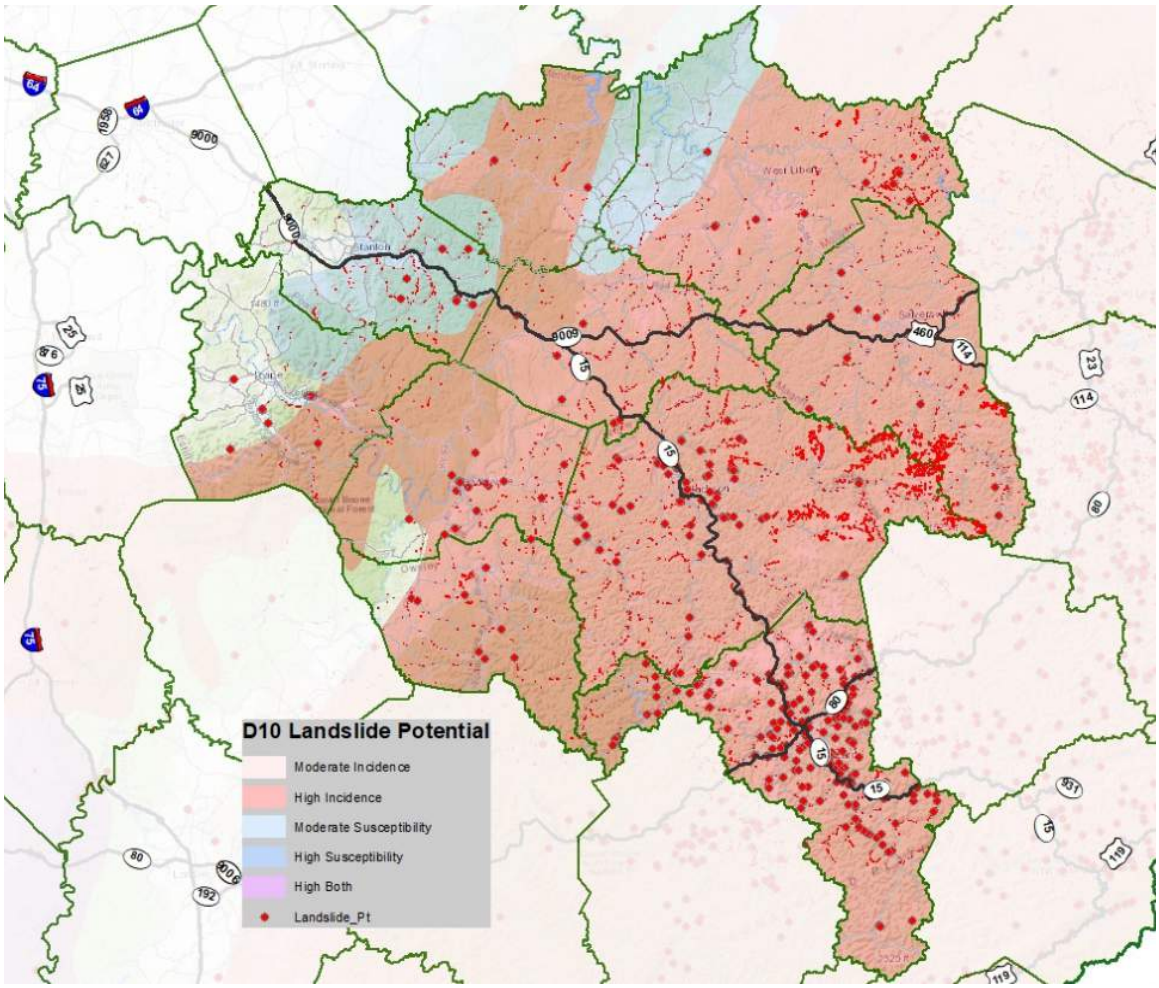


Figure 10-4. Landslide incidence and susceptibility in KYTC District 10

Within the KGS landslide inventory database, landslides have been documented at the following locations on the NHS:

- Slide Corrections on KY 9009at MPs 36.05 EB, 36.4 EB, 38.5 WB, 41.3 WB; Wolfe County.
- Landslide KY 9009 MP 65; Magoffin County.
- Landslide KY 9009 MP 66; Magoffin County.
- Rockfall US 460; Magoffin County.
- Rockfall KY 114 MP 2.2; Magoffin County.
- Rockfall KY 15 MP 17.65; Breathitt County.
- Rockfall KY 15 MP 15.9; Breathitt County.
- Rockfall Briar Fork Circle Rd; Perry County.
- Landslide HR 9006 MP 53.9; Perry County.

10.2.4. Karst

Sinkholes are a minor hazard in District 10. The majority of the district is not located in karst-prone areas. Only northwestern parts of the district in Estill, Powell, Menifee, Morgan, and Lee have the potential for karst formation. Within these areas, most sinkholes are located along or near the Estill/Powell and Estill/Lee county lines. District 10 has 2 miles of NHS highway located in areas of high karst potential, this being a small section of the Mountain Parkway in Powell County.

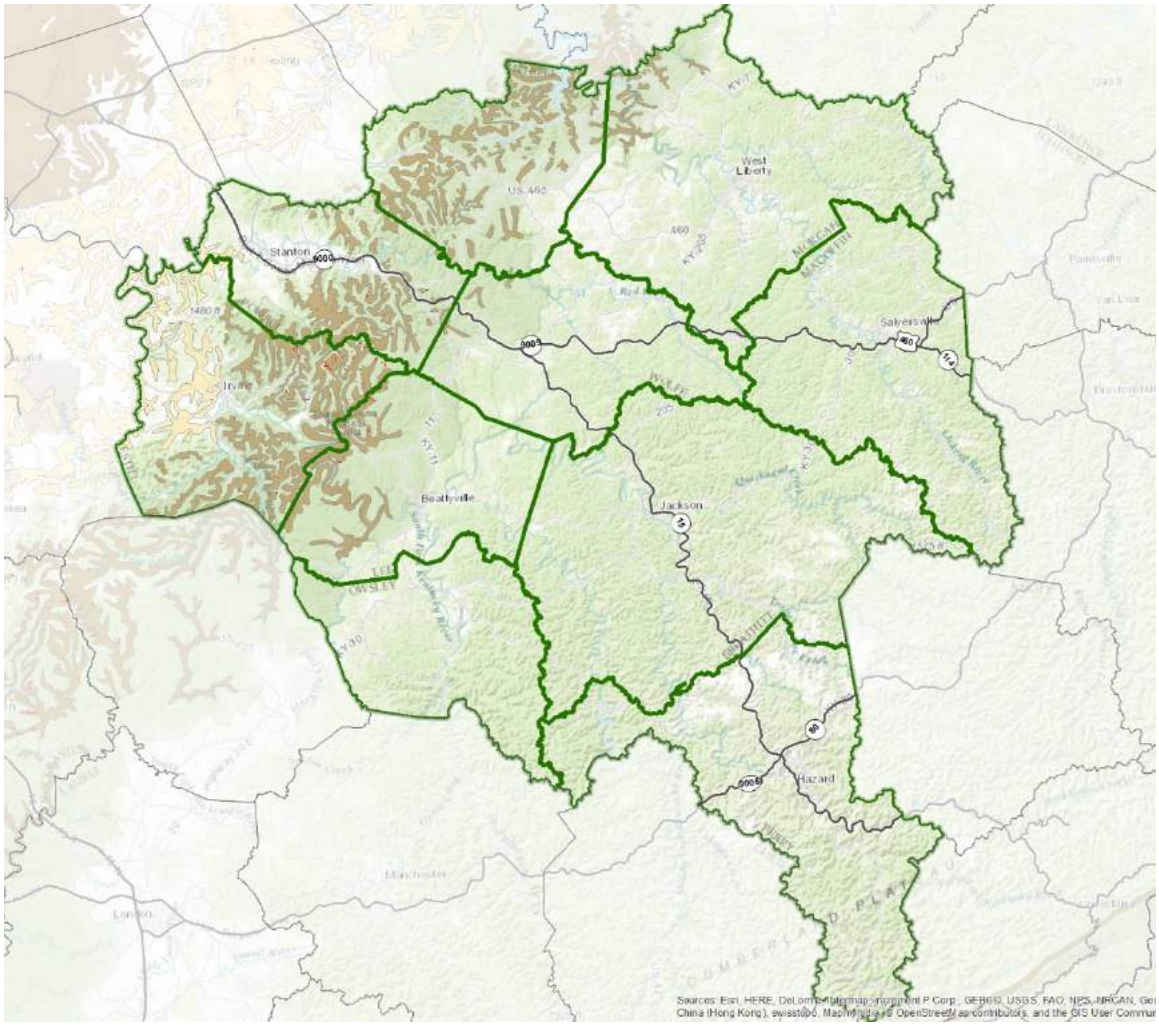


Figure 10-5. Karst potential and sinkholes in KYTC District 10

10.2.5. Other Meteorological Hazards

- Snow/Ice: All areas of District 10 average between 12” and 16” of annual snowfall, which is somewhat higher than the overall state average.
- Freeze/thaw: District 10 counties average between 85 and 97 annual freeze/thaw days. This average is considerably higher than the overall state average.
- Extreme heat: District 10 counties average 1-2 days annually where the temperature exceeds 95 degrees Fahrenheit, compared to the statewide average of 4 such days annually. Areas to the north of the District, including Menifee and Morgan Counties, average the most days, while Owsley County and Perry County in the south average the fewest.

- Drought/wildfire: Wildfires are more common in District 10 compared to the rest of the state. For the years 2002 to 2016, the district averaged nearly 20 documented wildfires each year. While most of these were small and their impacts minimal, several were significant. Several significant wildfires occurred in 2016: a wildfire in Breathitt County near the Lee County line burned 1,746 acres; a wildfire in Breathitt County just south of Jackson burned 1,753 acres; and a wildfire in Powell County along and just north of the Mountain Parkway near Slade burned 307 acres.
- Tornado: Compared to other districts in the state, District 10 has low vulnerability to tornadoes. From 1950 to 2015, District 10 had 19 tornadoes overall, and 3 of intensity F3 and above tornadoes. Both of these totals rank District 10 eleventh out of the twelve KYTC districts in terms of tornado vulnerability.

10.3. Workshop

The research team conducted a facilitated workshop in District 10 in October 2017. Seven KYTC personnel attended the workshop. During the workshop, data was collected from participants through a series of facilitated events, including; a) two keypad exercises where participants were asked to score the criticality of the roadway and the potential impacts of an extreme weather and/or natural hazard event, b) a mapping exercise with a focused conversation to contextualize flooding events in the District, and c) a consensus workshop where participants identified and discussed challenges to performing transportation system maintenance.

10.3.1. Polling Results

For workshop mapping purposes, the NHS in the district was divided into 13 functional roadway segments based upon road designation and county location. Participants were provided with keypads and asked to evaluate each of the NHS segments for criticality and potential impacts from extreme weather and natural hazards. An overall vulnerability score for each segment was computed by multiplying together the criticality and impacts ratings. The vulnerability score, then, provides a metric for identifying highway segments that are both the most important and could potentially suffer the most damage from natural hazards. Table 10-2 displays the results of the workshop keypad assessments. The final column ranks each segment by the vulnerability score.

Table 10-2. District 10 workshop polling results showing criticality, impacts, and vulnerability

Segment ID	Segment Description	Criticality	Impacts	Vulnerability	Rank
1	Mountain Parkway: Powell County	8.4	5.9	49.4	3
2	Mountain Parkway Wolfe County from KY 15 to Powell County	8.4	4.3	36.5	9
3	Mountain Parkway Wolfe County from KY 15 to Morgan County	7.7	4.6	35.3	10
4	KY 15: Wolfe County	8.1	5.0	40.7	7
5	Mountain Parkway: Morgan County	8.0	4.6	36.6	8
6	Mountain Parkway: Magoffin County	8.0	4.3	34.3	12
7	US 460: Magoffin County from Mtn Parkway to Johnson County	7.0	4.1	29.0	13
8	KY 114: Magoffin County	7.6	4.6	34.6	11
9	KY 15: Breathitt County	8.6	5.7	49.0	4
10	KY 15: Perry County from CR 1411 to Breathitt County line	8.6	6.2	52.9	1
11	KY 15: Perry County from CR 1411 to Knox County line	8.3	6.0	49.7	2
12	Hal Rogers Parkway: Perry County	8.4	5.1	43.3	5
13	KY 80: Perry County from KY 15 to Knox County line	8.3	5.1	42.6	6

10.3.2. Map Exercise

Workshop participants were asked to review and mark-up eight detailed maps of the NHS in District 10. The maps included NHS roadway segments and the associated bridges, culverts, and other structures; other state highways; streams, rivers, and other bodies of water; and the 100-year floodplain. Participants were asked to mark the maps and provide as much detail as possible for areas along the NHS that have A) flooded in the past, B) have been close to flooding in the past, and C) are likely to flood during an extreme weather event. Table 10-3 displays the results of this exercise.

Table 10-3. District 10 NHS segments and flood

District	County	MP	Route	Hazard	Intersecting feature
10	Magoffin	0	KY-9009	Has flooded	Licking River
10	Breathitt	3.4	KY-15	Has flooded	Lost Creek
10	Breathitt	0	KY-15	Has flooded	KY-15 at Lost Creek
10	Powell	24.4	KY-9000	Has flooded	Red River Backwater
10	Powell	16.3	KY-9000	Has flooded	Bush Creek
10	Morgan	62.7	KY-9009	Has flooded	Johnson Creek
10	Magoffin	64.25	KY-9009	Has nearly flooded	Johnson Creek

10.3.3. Workshop discussion

Flooding and landslide are the two most common hazards in District 10, and district personnel talked extensively about these problems in the workshop. Areas of District 10 experience flooding in two forms: flash flooding and backwater river flooding. Flash flooding is the more dangerous and destructive of the two, but these events are short in duration. Backwater river flooding does not have the same destructive power, but these flood events can be much longer in duration, resulting in road closures for days.

The Mountain Parkway at the Clay City interchange was reported to flood five to six times a year. Though the flooding causes road closures on the parkway, the impacts are minimal as cars are able to take the exit/entrance ramps around the flooded and closed section of the road.

District 10 has several methods for mitigating against landslides and shoring up roadbeds located along stream. The most commonly used method is to drill rail steel along the roadbed to increase stability. This technique is most effective if the rail steel can be drilled into bedrock beneath the slip and the length of the slide is less than 20 feet. Drilling rail steel is not a permanent fix, as it generally has a shelf life of about 30 years. It also adds weight to the embankment, which can lead to more pressure and more slipping. In locations where steel cannot be drilled into the bedrock, soil nails can be used in combination with concrete to mitigate against slips.

10.3.4. Roadways outside of the NHS that flood

District 10 personnel identified roads outside of the NHS that flood in all areas of the district. Because of the steep mountainous topography in much of District 10, roads are commonly built along stream channels in the valleys. This makes such roads particularly vulnerable to flash flooding as well as vulnerable to erosion and the road bed slipping off toward the streams. District personnel stated that pretty much all Rural Service routes in the district are vulnerable to flash flooding because of these problems. Larger highways and more recently built roads are for the most part are constructed to higher design standards, though even they have some vulnerability to flooding and slipping.

The following are some of the more prominent flood events discussed in the workshop. In 2015, a woman was killed when her car was swept away by floodwater on KY-52 near Beattyville. The town of Wolverine is located along the North Fork Kentucky River and floods frequently. A bridge that serves as a major access point to the town on KY-3193 is particularly vulnerable. Backwater from the Licking River floods US-460 in Salyersville, though a project by US Army Corps of Engineers is ongoing to try and fix the problem. The city of Hazard was built on a floodplain and floods frequently, including a truss bridge on KY-451 over the North Fork Kentucky River. Backwater from Cave Run Lake frequently closes roads, including KY-2498 – a critical access road to a regional hospital.

10.3.5. Maintenance facilities flooding

The District 10 maintenance and facilities in Morgan County have experienced flooding issues in the past, with water flooding the facilities every couple of years. No other KYTC facilities in District 10 were believed to have any flood problems.

10.3.6. Consensus workshop

For the consensus workshop, participants were asked to individually brainstorm about the following question; “What are the Biggest Challenges to Performing Maintenance in District 10?” Participants were asked to work in small groups to discuss and clarify their ideas. Ideas were then presented and group with all the participants. Table 10-4 provides the participants answers to the consensus workshop question.

Table 10-4. Results of District 10 consensus workshop

Identified Challenges to Conducting Maintenance Operations in District 10				
Disconnect with Upper Management	**Better Methods for Getting Equipment**	**Some People Suck**	**Difficult Terrain**	**Money**
	Equipment	Personnel (Training, Attitudes, Dependability)	Topography/Terrain	Funding
	Equipment Issues	Training	Terrain	Need more funding
	Availability of Equipment (Sharing between counties)	Number of Employees	Lots of stuff -Drainage structures -Ditches	Funding
	Scheduling Shared Contractors	Merit System	Lots of trees Sight Distance	
		Retaining Good Employees	Extreme weather conditions	
		Manpower People/Contractors	Many miles of secondary roads	

10.4. Results

10.4.1. Identification of most at vulnerable assets

Table 10-5 lists District 10 NHS assets with a vulnerability score of 3.5 or greater for any of the four major hazards in this analysis (a full list of District 10 NHS assets and vulnerability scores is in Appendix 2). Landslide is the one hazard that causes the greatest vulnerability in District 10, with the Hal Rogers Parkway (HR-9006) in Perry County having the highest overall vulnerability score. KY-15 through Breathitt County and Perry County also has a high landslide vulnerability score, and this is reflected in both the overall findings and the workshop keypad scoring.

Table 10-5. District 10 NHS assets with vulnerability score 3.5 or greater

District	County	Route	Vulnerability Score	Hazard
10	Perry	KY 80	**3.53**	Landslide
10	Wolfe	KY 9000	**3.53**	Landslide
10	Magoffin	KY 114	**3.58**	Landslide
10	Magoffin	KY 9009	**3.58**	Landslide
10	Magoffin	US 460	**3.60**	Landslide
10	Breathitt	KY 15	**3.67**	Landslide
10	Perry	KY 15	**3.67**	Landslide
10	Wolfe	KY 9009	**3.67**	Landslide
10	Perry	HR 9006	**3.75**	Landslide

10.4.2. Worst case scenario

A massive flash flood event would be the worst case scenario for District 10. Flash flooding has the potential to wipe out bridges, wash out roads, flood and wash away homes and structures, and trigger erosion and landslides. Because most towns are located in low-lying areas along streams and rivers, such flash flooding could occur throughout the district. Historical climate data suggests that the mountains of eastern Kentucky are less likely to experience extreme rainfall events compared to other areas of the state. Though they may occur infrequently, the impacts are usually significant.

11. KYTC District 11

11.1. District Overview

KYTC District 11 is in southeastern Kentucky and includes the counties of Bell, Clay, Harlan, Jackson, Knox, Laurel, Leslie, and Whitley. District 11 is another largely rural and mountainous region of Kentucky. The largest city in the district is Middlesboro with a population of 9,626[23]. The southern edge of the district forms the state border with Tennessee, while the southeastern edge forms the border with Virginia. Rivers in District 11 include the Cumberland River, Laurel River (and Laurel River Lake), Rockcastle River, Southern Fork Kentucky River, and Middle Fork Kentucky River. District 11 is in the Cumberland Plateau physiographic region, which encompasses the Appalachian Mountains from Pennsylvania to Alabama. The Cumberland Plateau region is characterized by forested hills and highly dissected by V-shaped valleys. Mountains of significance in District 11 include Black Mountain, which is the highest point in Kentucky at elevation 4145 feet, and Pine Mountain.

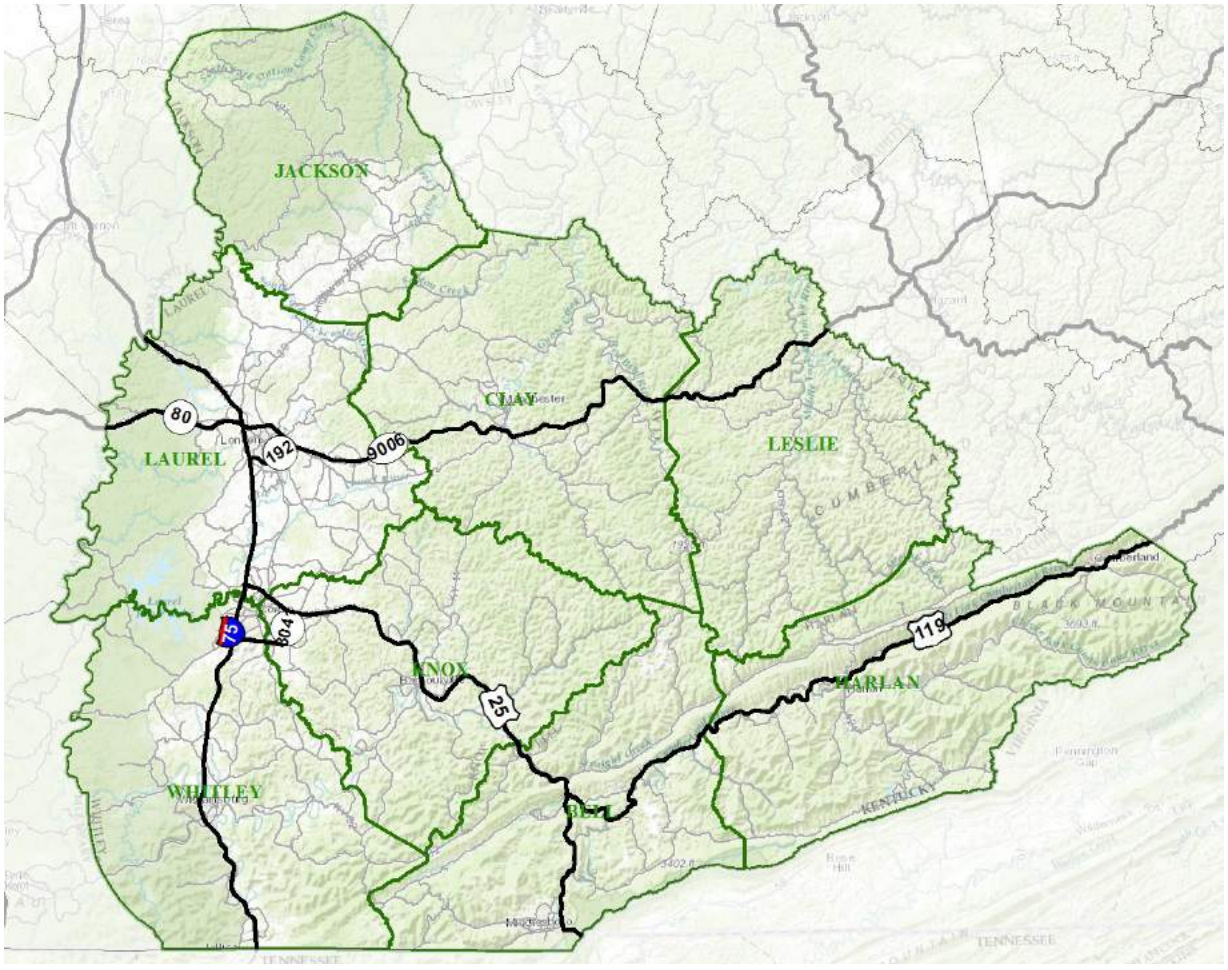


Figure 11-1. KYTC District 11 NHS

[23] U.S. Census Bureau, Population Division.

The District 11 NHS is comprised of 344 centerline miles of roadway, which is the second fewest of any district in the state. District 11 NHS includes I-75 in Laurel and Whitley counties and the Hal Rogers Parkway (HR-9006) in Laurel, Clay, and Leslie Counties. US Highways include US-25, running from I-75 to the Virginia border (including the Cumberland Tunnel), and US-119 in Bell and Harlan counties. The NHS in District 11 includes 73 bridges, 17 culverts, and 67 structures.

11.2. Hazards

District 11 NHS assets, including highway segments, bridges, culverts, and other structures were assessed against the four primary hazards identified for this project: earthquake, flood, sinkhole, and landslide. Table 11-1 summarizes the relationship between these NHS assets and selected natural hazard indicators.

Table 11-1. Summary of KYTC District 11 NHS assets and natural hazard indicators

Asset Type	D11 Total	PGA ≥ 60 (Destructive)	PGA ≥ 30 and < 60 (Very Strong)	PGA ≥ 18 and < 30 (Strong)	In Flood Plain	Major Karst	Moderate Karst	High Landslide Susceptibility	Moderate Landslide Susceptibility
Total Road Miles	344	0	0	152	12	1	0	254	5
Interstate	111	0	0	36	4	0	0	57	0
Parkway	53	0	0	0	6	0	0	48	3
US	149	0	0	116	2	1	0	143	1
KY	31	0	0	0	0	0	0	6	1
Local Road	0	0	0	0	0	0	0	0	0
Bridges	73	0	0	35	16	1	0	63	1
Culverts	17	0	0	6	8	0	0	16	1
Structures	67	0	0	24	5	0	0	45	1

11.2.1. Earthquake

District 11 has some vulnerability to earthquake due to its proximity to the Eastern Tennessee Seismic Zone. Figure 11-2 shows where District 11 lies relative to USGS defined PGA zones. District 11 lies within PGA zones that range from 8 to 20. A PGA rating of 18 to 20 compares to "Very Strong" on the Modified Mercalli-Scale and is described as "Mild alarm; walls crack; plaster falls." A PGA rating of 9 to 18 roughly equates to "Strong" on the Modified Mercalli-Scale, and is described as "Trees sway; suspended objects swing; objects fall off shelves." District 11 NHS assets lying in PGA Zones 18 and 20 include US 25 in Bell County and Knox County, US 119 in Harlan County, and US-41A and I-75 in southern Whitley County.

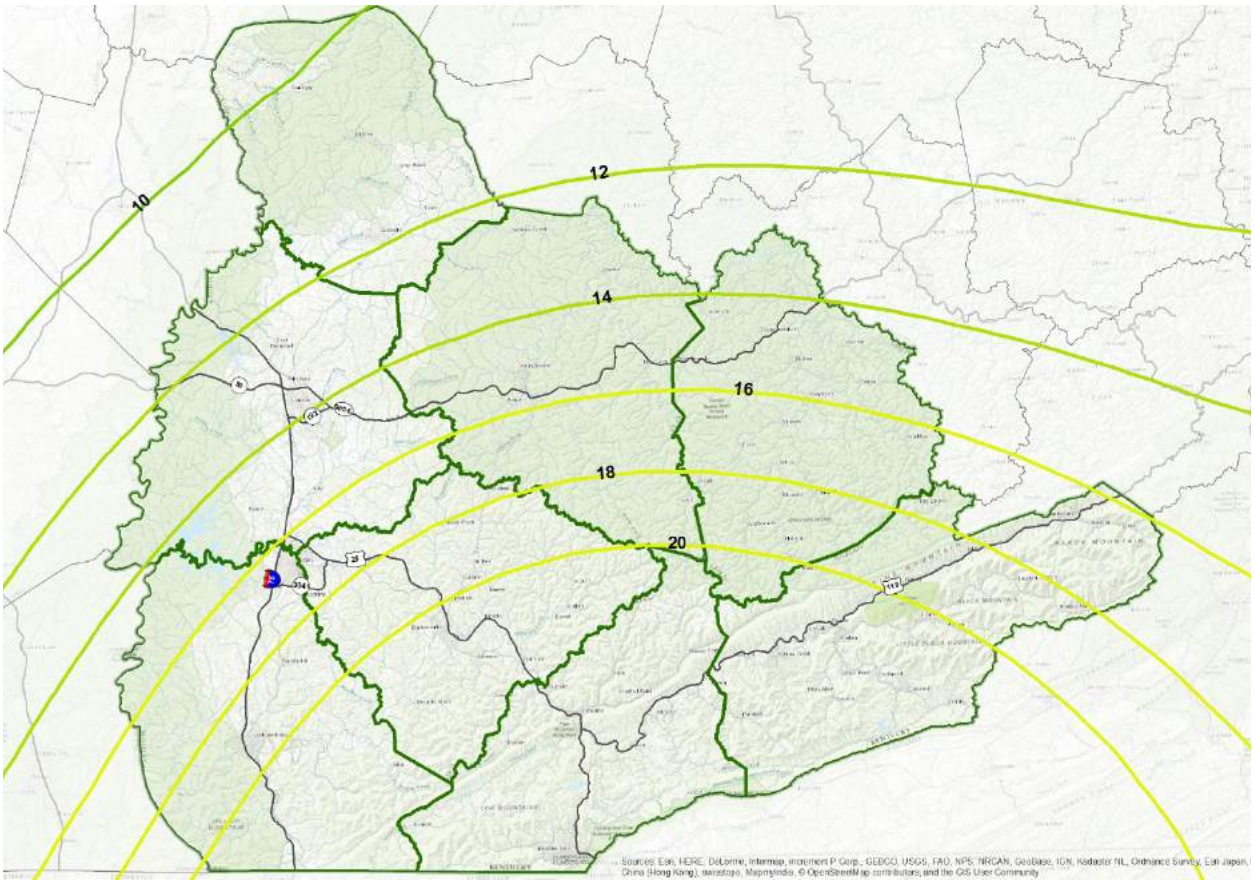


Figure 11-2. USGS PGA Zones in KYTC District 11

11.2.2. Flood

District 11 is drained by two river systems. The majority of the region is drained by the Cumberland River system, with streams in this system flowing primarily westward. Northeastern areas of the district are drained by the Kentucky River system, with streams in this system flowing northward. In all, District 11 has 12 miles of NHS roadway located in the 100-year floodplain. Other NHS assets located in the 100-year floodplain include 16 bridges, 8 culverts, and 5 other structures.

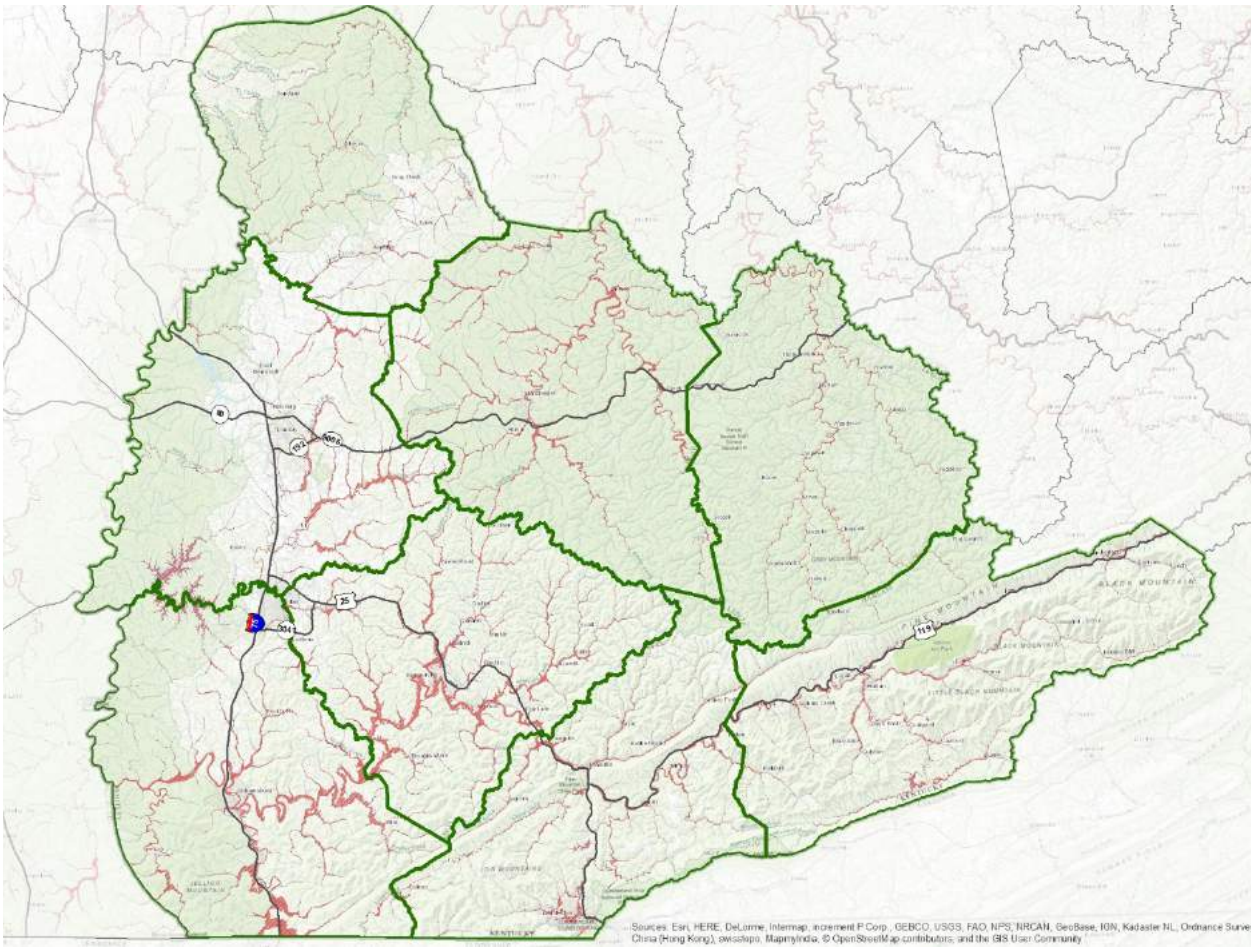


Figure 11-3. KYTC District 11; location of 100-year floodplain

From 1981 to 2015, counties in District 11 experienced extreme rainfall events (greater than 3" of rain in a single calendar day) on average every five to eight years, compared to the statewide average of an extreme rainfall event every four years.

11.2.3. Landslide

Landslides are a major hazard in District 11. Figure 11-4 is a map of landslide susceptibility and incidences in District 11. Landslides are common throughout the district within counties to the east. Leslie County, Harlan County, and Bell County have the highest totals.

District 11 has 254 miles of NHS highway located in areas identified by USGS as having high landslide incidence. Of these, 57 are interstate miles, 48 are parkway miles, 143 are US highway miles, and 6 are KY highway miles. Other NHS assets located in these areas of high landslide susceptibility include 63 bridges, 16 culverts, and 45 other structures.

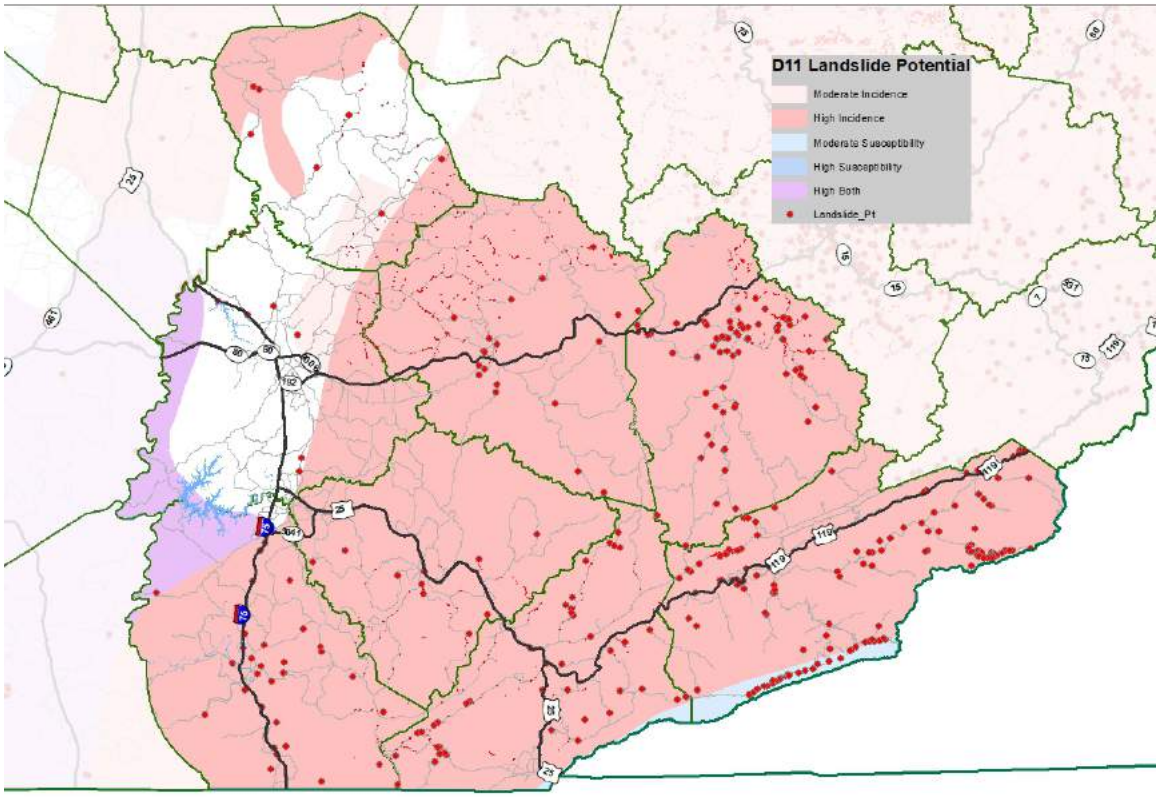


Figure 11-4. Landslide incidence and susceptibility in KYTC District 11

Within the KGS landslide inventory database, landslides have been documented at the following locations along the NHS:

- Landslide correction I-75 MP 45; Laurel County
- Landslide I-75 MP 48.1; Laurel County
- Mudslide KY 25W MP 16; Whitley County
- Rockfall I-75 MP 20, MP 14, MP 23; Whitley County
- Landslide correction US 25W MP 8.4; Whitley County
- Landslide I-75 MP 3.985 below interstate in fill embankment; Whitely County
- Rockfall US 25 MP 10.6; Knox County
- Landslide US 25 MP 14.8; Knox County
- Landslide US 25E; Bell County
- Embankment landslide US 119 MP 8.7; Harlan County
- Rockfall KY 3467 at intersection of US 119; Harlan County
- Landslide US 119 at intersection of US 421; Harlan County
- Landslide on US 119 approx. 1.3 Miles Northwest of Harlan; Harlan County

11.2.4. Karst

Sinkholes are a minor hazard in District 11. The majority of the district is not located in karst-prone areas. Only northern parts of the district in Jackson County and a thin band along Pine Mountain in Whitley, Bell, and Harlan Counties have the potential for karst formation. Within those areas, some sinkholes have been documented in northern Jackson County. District 10 has 1

mile of NHS highway located in areas of high karst potential, this being a small section of US 25 in Bell County.

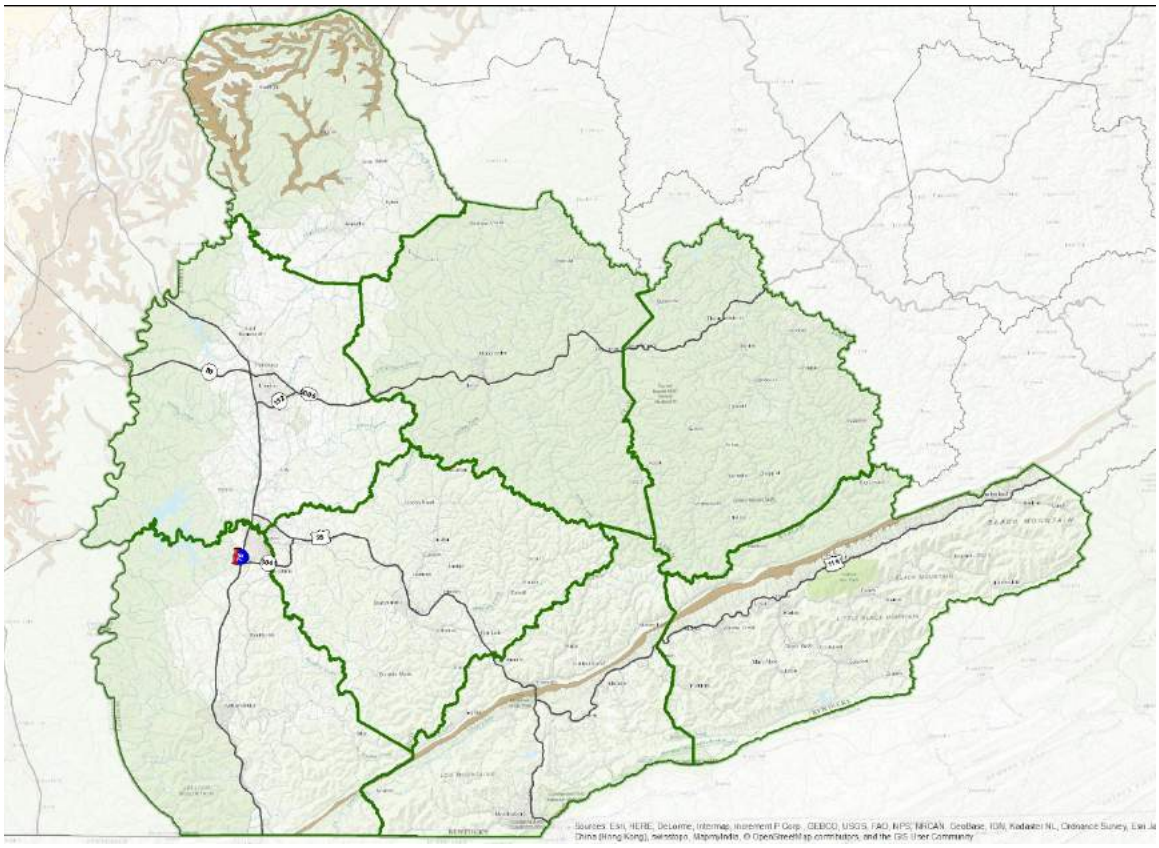


Figure 11-5. Karst potential and sinkholes in KYTC District 11

11.2.5. Other Meteorological Hazards

- Snow/Ice: District 11 annual snowfall averages vary significantly from west to east. Western and central areas of the district average 10” to 12” of snowfall annually, which is near average for the state. Moving eastward in the district, the annual snowfall totals rise steadily, with eastern parts of Harlan County averaging greater than 20” annual snowfall. These totals along the Virginia border moving eastward from Harlan County are highest in the state.
- Freeze/thaw: District 11 counties average between 88 and 98 annual freeze/thaw days. These averages are higher than the overall state average of 84 freeze/thaw days per year.
- Extreme heat: District 11 counties average one day or less annually where the temperature exceeds 95 degrees Fahrenheit, compared to the statewide average of 4 such days annually. Harlan County has the lowest average in the state at 0.2 days with temperature exceeding 95 degrees per year.
- Drought/wildfire: Wildfires are more common in District 11 compared to the rest of the state. For the years 2002 to 2016, the district averaged nearly 20 documented wildfires each year. While most of these were small and their impacts minimal, several were significant. In 2016: a wildfire in eastern Harlan County south of Cumberland burned 1,740 acres. Also

in 2016, a wildfire in southwestern Leslie County burned 380 acres. In 2014, a wildfire in western Whitley County burned 339 acres.

- Tornado: District 12 has the lowest vulnerability to tornadoes of any KYTC district. From 1950 to 2015, District 12 experienced 6 tornadoes overall, 2 of which were of intensity F3 and above. Both of these totals are lowest of all KYTC district. Since 1950, no tornadoes have been documented in either Letcher County or Floyd County.

11.3. Workshop

The research team conducted a facilitated workshop in District 11 in June 2017. Eleven KYTC personnel attended the workshop. During the three hour workshop, data was collected from participants through a series of facilitated events, including; a) two keypad exercises where participants were asked to score the criticality of the roadway and the potential impacts of an extreme weather and/or natural hazard event, b) a mapping exercise with a focused conversation to contextualize flooding events in the District, and c) a consensus workshop where participants identified and discussed challenges to performing transportation system maintenance.

11.3.1. Polling Results

The District 11 NHS was divided into 14 segments based upon road designation and county location. Workshop participants were provided with keypads and asked to evaluate each of the NHS segments for criticality and potential impacts from extreme weather and natural hazards. An overall vulnerability score for each segment was computed by multiplying together the criticality and impacts ratings. The vulnerability score, then, provides a metric for identifying highway segments that are both the most important and could potentially suffer the most damage from natural hazards. Table 11-2 displays the results of the workshop keypad assessments. The final column ranks each segment by the vulnerability score.

Table 11-2. District 11 workshop polling results showing criticality, impacts, and vulnerability

Segment ID	Segment Description	Criticality	Impacts	Vulnerability	Rank
1	I-75: Laurel County	8.7	8.4	73.1	2
2	KY 80: Laurel County from US 25 to Pulaski-County line	7.5	5.4	41.1	8
3	Hal Rogers Parkway: Laurel County	7.7	4.9	37.9	9
4	KY 192: Laurel County east of I-75	6.9	4.2	29.0	12
5	Hal Rogers Parkway: Clay County	7.7	5.4	41.5	7
6	Hal Rogers Parkway: Leslie County	7.3	5.1	37.3	10
7	I-75: Whitley County	8.7	8.4	73.3	1
8	KY 3041/ US 25W: Corbin Bypass Whitley County & I-75 connect	5.8	3.1	18.0	13
9	KY 3041: Corbin Bypass Knox County	5.7	2.9	16.6	14
10	US 25E: Laurel County	7.4	5.0	36.8	11
11	US 25E: Knox County	8.0	5.3	42.4	6
12	US 25E: Bell County	8.2	6.5	53.2	5
13	US 119: Bell County	8.4	7.6	63.6	4
14	US 119: Harlan County	8.2	7.9	64.6	3

11.3.2. Map Exercise

Workshop participants were asked to review and mark-up eight detailed maps of the NHS in District 11. The maps included NHS roadway segments and the associated bridges, culverts, and other structures; other state highways; streams, rivers, and other bodies of water; and the 100-year floodplain. Participants were asked to mark the maps and provide as much detail as possible for areas along the NHS that have A) flooded in the past, B) have been close to flooding in the past, and C) are likely to flood during an extreme weather event. Table 11-3 displays the results of this exercise.

Table 11-3. District 11 NHS segments and flood

District	County	MP	Route	Hazard	Intersecting feature
11	Harlan	14.5	US-119	Has flooded	KY 413

11.3.3. Workshop discussion

Like other KYTC districts in eastern Kentucky, District 11 is most vulnerable to flooding and landslide. In 1977 this area of eastern Kentucky experienced some of the worst flooding in memory. A multi-day rainfall event dropped 6 to 10 inches of precipitation across a large area along the Kentucky/Virginia border, flooding multiple rivers and towns in eastern Kentucky and western Virginia. Flooding on the Cumberland River completely subsumed the town of Pineville under several feet of water. Historical climate data indicates that eastern Kentucky does not experience this type of heavy rainfall as often as other areas of the state, but when it does, the consequences can be catastrophic.

District personnel identified multiple areas of roadway that are affected by landslides in the form of rockfalls, debris flows, or slips. This includes several roadway segments on the NHS. US 119 in Harlan County and Bell County has several landslide areas. I-75 in Laurel County and Whitley County has several areas that are frequently impacted by rockfalls. On other state roads outside of the NHS, landslides are common. Leslie County was described as “one big red dot” (red dots indicated the location of landslides on a large printed map). KY 850 in Leslie County is particularly vulnerable. On the large map, district personnel drew a large circle around KY 92 in Whitley County as being a stretch of road where landslides are a major problem. In Bell County, KY 74 west of Middlesboro was described as having an “eternal problem” with landslides.

11.3.4. Roadways outside of the NHS that flood

In 2017, rainfall triggered a mudslide that covered and blocked KY-1344 in Bell County. KY 89 in Jackson County was reported to repeatedly experience flooding and slipping due to erosion. Road closures are particularly impactful here because the detour routes are all long, out of the way, and also vulnerable to flooding. In Laurel County, US 25 south of London floods frequently resulting in lane closures, but the flooding is generally minor and short-lived. In Knox County, KY 459 floods frequently. When the flooding results in road closure, schools in Barbourville are closed due to inaccessibility. In Whitley County, KY 1804 often is blocked by floodwater. Road closures here can last several days. Also in Whitley County, KY 2996 is sometimes blocked by floodwater, resulting in several houses being cut-off from the rest of the transportation network.

11.3.5. Maintenance facilities flooding

No maintenance facilities in District 11 were reported to flood.

11.3.6. Consensus workshop

For the consensus workshop, participants were asked to individually brainstorm about the following question; “What are the Biggest Challenges to Performing Maintenance in District 11?” Participants were asked to work in small groups to discuss and clarify their ideas. Ideas were then presented to the group. Table 11-4 provides the participants answers to the consensus workshop question.

Table 11-4. Results of District 11 consensus workshop

Identified Challenges to Conducting Maintenance Operations in District 11				
More Funding	**Need More Equipment: More Input of What is Actually Needed**	**Personnel: Summer Help...What Happened?**	**Environmental Issues**	**Compensation**
	More Equipment-Do Not Share	More Employees	Endangered Species	
	Equipment: -Lack of-Shared-Sizes	Traffic Control	Trees (Removal Fees)	
		Keep Equipment Running	Permits (Army Corps and DAE)	
		HIRE: Workers, Mechanics Needed		

11.4. Results

11.4.1. Identification of most at vulnerable assets

Table 11-5 lists District 11 NHS assets with a vulnerability score of 3.5 or greater for any of the four major hazards in this analysis (a full list of District 11 NHS assets and vulnerability scores is in Appendix 2). Flood and landslide are the two hazards that cause the greatest vulnerabilities in District 11. I-75 in Whitley County is scored as having the greatest vulnerability to both flooding and landslide. These results mirror those from the workshop keypad scoring exercises, where I-75 in Whitley County was similarly scored as the most vulnerable NHS asset in the district. All five of the highest scored assets from the workshop keypad exercises on asset vulnerability also appear in the overall findings as among the most vulnerable.

Table 11-5. District 11 NHS assets with vulnerability score 3.5 or greater

District	County	Route	Vulnerability Score	Hazard
11	Whitley	I-75	**3.79**	Flood
11	Knox	US 25E	**3.57**	Landslide
11	Laurel	I-75	**3.67**	Landslide
11	Bell	US 119	**3.68**	Landslide
11	Bell	US 25E	**3.68**	Landslide
11	Harlan	US 119	**3.68**	Landslide
11	Whitley	I-75	**3.87**	Landslide

11.4.2. Worst case scenario

Because of the importance of I-75 to the overall transportation system, any damage and disruption to that asset would constitute the worst case scenario for District 11. Just south of the state line in Tennessee, major landslides and rockfalls have resulted in closure of I-75. In 2012, a landslide closed I-75 for several months. Again in 2016, a rockfall closed the interstate for several weeks.

12. KYTC District 12

12.1. District Overview

KYTC District 12 is in southern Kentucky and includes the counties of Floyd, Johnson, Knott, Lawrence, Letcher, Martin, and Pike. District 12 is largely rural, with Pikeville (population 7,106[24]) being the largest city and home to the KYTC District offices. In terms of total population, District 12 has the second lowest population of all KYTC districts. The northeastern edge of the district forms the state border with West Virginia, while the southeastern edge of the district forms the border with Virginia. Rivers in District 12 include the Big Sandy River, Levisa Fork, and the headwaters of the Cumberland River and Kentucky River. District 12 is in the Cumberland Plateau physiographic region, which encompasses the Appalachian Mountains from Pennsylvania to Alabama. The Cumberland Plateau region is characterized by forested hills and mountains that are highly dissected by V-shaped valleys.

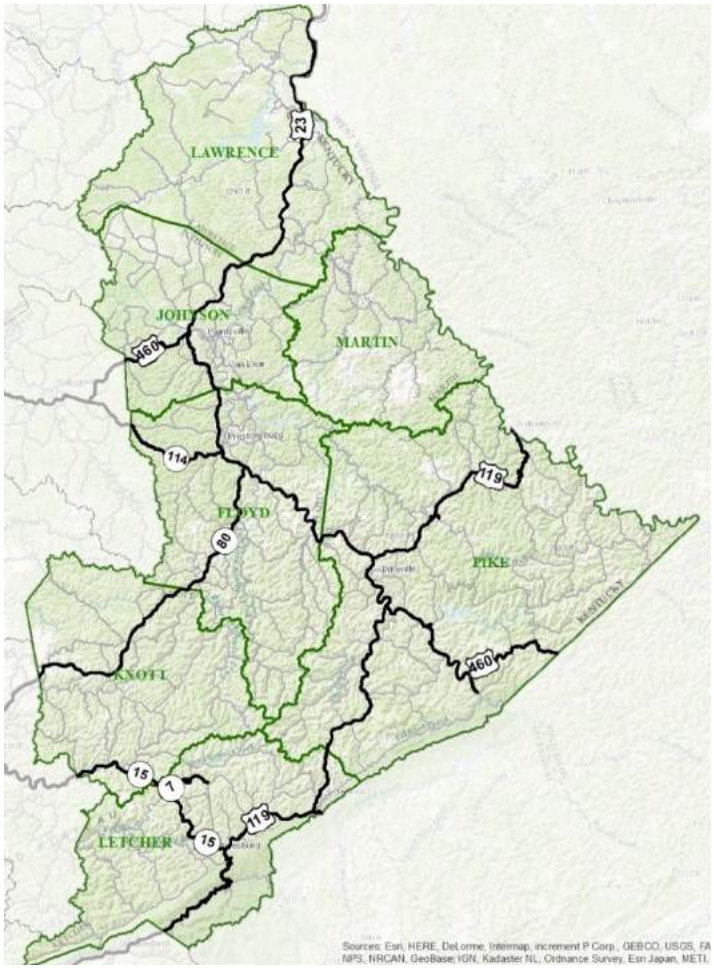


Figure 12-1. KYTC District 12 NHS

The District 12 NHS is comprised of 462 centerline miles of roadway, which is the sixth most of any district in the state. District 12 NHS does not include any interstate or parkway miles. US

[24] U.S. Census Bureau, Population Division.

Highways include US-23 from Lawrence County to the Virginia line in Letcher County, US-119 in Pike and Letcher counties, and US-460 in Pike and Johnson counties. The NHS in District 12 includes 66 bridges, 29 culverts, and 24 structures.

12.2. Hazards

District 2 NHS assets, including highway segments, bridges, culverts, and other structures were assessed against the four primary hazards identified for this project: earthquake, flood, sinkhole, and landslide. Table 12-1 summarizes the relationship between these NHS assets and selected natural hazard indicators.

Table 12-1. Summary of KYTC District 12 NHS assets and natural hazard indicators

Asset Type	D12 Total	PGA ≥ 60 (Destructive)	PGA ≥ 30 and < 60 (Very Strong)	PGA ≥ 18 and < 30 (Strong)	In Flood Plain	Major Karst	Moderate Karst	High Landslide Susceptibility	Moderate Landslide Susceptibility
Total Road Miles	462	0	0	0	30	5	0	460	0
Interstate	0	0	0	0	0	0	0	0	0
Parkway	0	0	0	0	0	0	0	0	0
US	345	0	0	0	25	5	0	344	0
KY	117	0	0	0	5	0	0	116	0
Local Road	0	0	0	0	0	0	0	0	0
Bridges	66	0	0	0	22	0	0	66	0
Culverts	29	0	0	0	11	0	0	29	0
Structures	24	0	0	0	0	0	0	24	0

12.2.1. Earthquake

The majority of District 12 does not lie within close proximity to any seismic zones and is not vulnerable to earthquakes. Southern parts of the district lie somewhat within proximity to the Eastern Tennessee Seismic Zone, though likely not close enough to experience any damage from an earthquake. Figure 12-2 shows where District 12 lies relative to USGS defined PGA zones. The majority of District 12 lies in PGA Zones 8 and 10. Southern parts of Knott and Pike County and northern parts of Letcher County are in PGA Zone 12, while southern areas of Letcher County are in PGA Zones 14 and 16. A PGA zone of less than 18 compares on the Modified Mercalli-Scale to "Strong", which is described as "Sleepers awake; church bells ring." Seismic activity at this level would not be expected to negatively impact NHS assets in District 12.

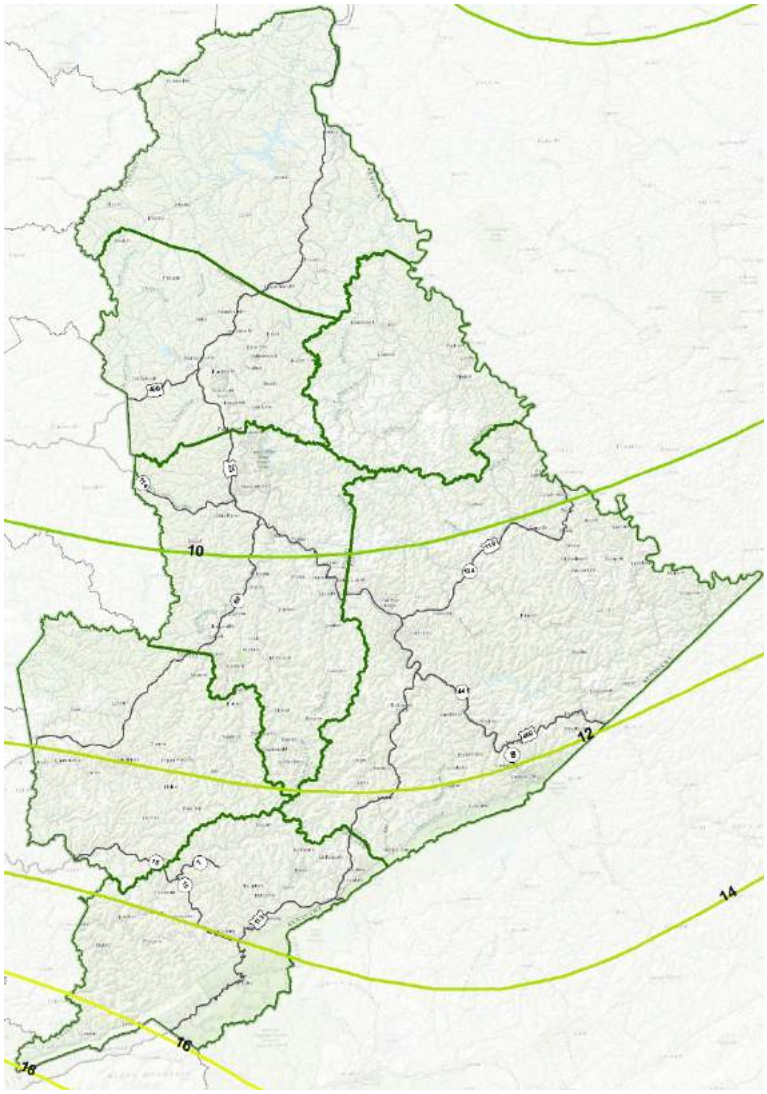


Figure 12-2. PGA Zones in KYTC District 12

12.2.2. Flood

District 12 is drained by several large river systems. The majority and northern extent of the region is drained by the Big Sandy River system, with streams, including Levisa Fork and Tug Fork, in

this system flowing north and eastward. Most of Knox County and Letcher County are drained by the Kentucky River system, while a small section of US 119 in Letcher County lies along the Poor Fork of the Cumberland River. In all, District 12 has 30 miles of NHS roadway located in the 100-year floodplain. Additional NHS assets located in the 100-year floodplain are 22 bridges and 11 culverts.

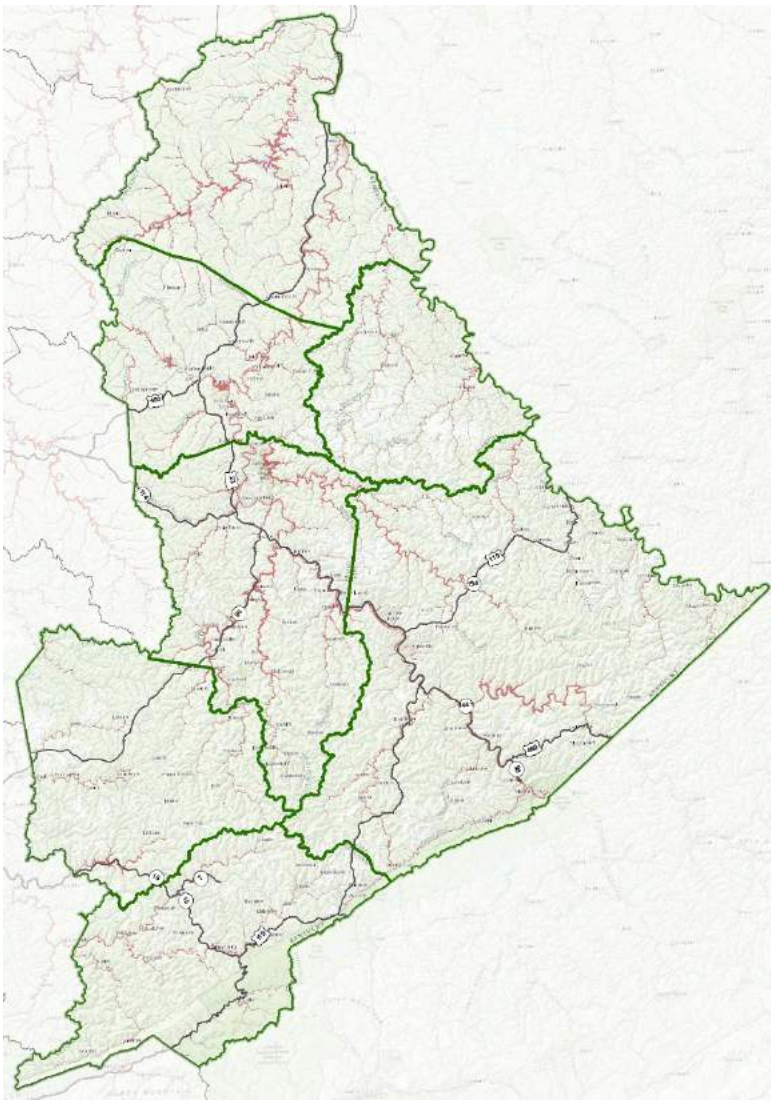


Figure 12-3. KYTC District 12 100-year floodplain

From 1981 to 2015, District 12 experienced fewer extreme rainfall events (greater than 3" of rain in a single calendar day) than any other KYTC district. On average, District 12 counties had such rainfall every twenty to twenty-five years, compared to the statewide average of an extreme rainfall event every four years. Pike, Johnson, and Martin counties experienced the fewest number of extreme rainfall days of any Kentucky counties during this time period.

12.2.3. Landslide

Landslides are a major hazard in District 12, and this hazard is prevalent throughout the district. Figure 12-4 is a map of landslide susceptibility and incidences in District 12. In all, District 12 has

460 miles of NHS highway located in areas identified by USGS as having high landslide incidence. Of these, 344 are US highway miles, and 116 are KY highway miles. Other NHS assets located in these areas of high landslide incidence include 66 bridges, 29 culverts, and 24 other NHS structures.

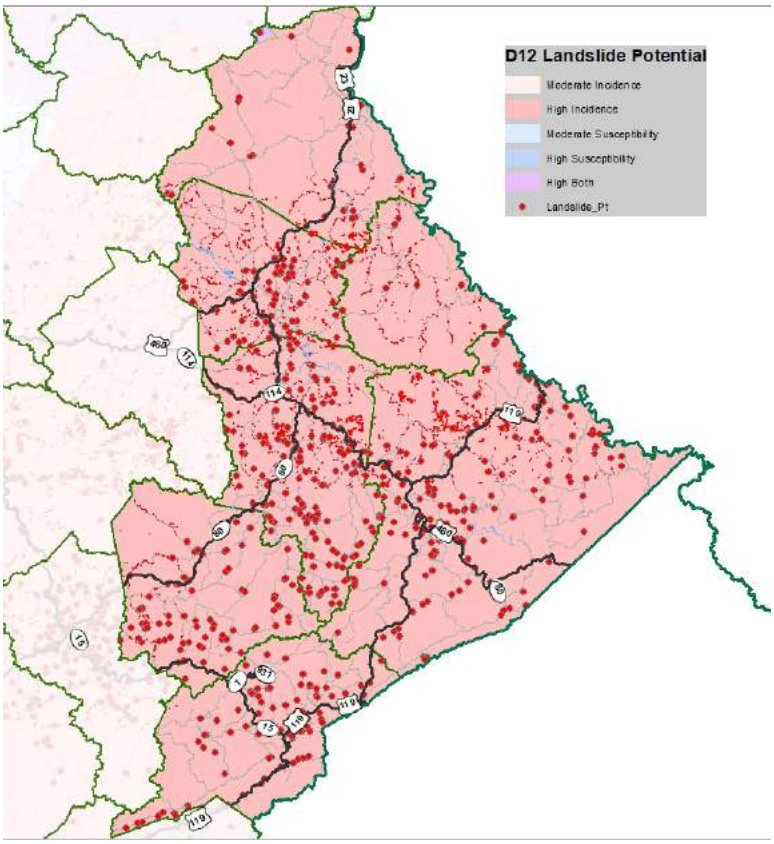


Figure 12-4. Landslide incidence and susceptibility in KYTC District 12

Within the KGS landslide inventory database, landslides have been documented at the following locations along the NHS:

- Landslide US 23 near Lomansville; Lawrence County
- Landslide Correction on US 23 MP 27.1 NB; Lawrence County
- Landslide US 23 MP 7.3; Lawrence County
- Landslide US 23 at intersection with KY 1100; Johnson County
- Landslide KY 2555 MP 0.044; Floyd County
- Rockfall KY 114 MP 2.6; Floyd County
- Landslide KY 23 near Allen; Floyd County
- Landslide on Pennington Ln of US 23; Floyd County
- Landslide US 23 MP 8 NB, road closed; Floyd County
- Rockfall US 23 MP 7; Floyd County
- Rockfall KY 80 MP 8.8, Floyd County
- Rockfall KY 80 between MP 9 and MP 10; Floyd County
- Landslide KY 80 MP 1.5; Knott County

- Landslide KY 80 MP 8.5; Hindman County
- Mudslide KY 15 MP 6.2; Knott County
- Rockfall US 23 MP 27.1 NB; Pike County
- Landslide US 119 multiple location between MP 23.5 and MP 31; Pike County
- Landslide US 460; Pike County
- Rockfall US 460 MP 14; Pike County
- Landslide KY 1441; Pike County
- Landslide KY 80; Pike County

12.2.4. Karst

Sinkholes are not a significant hazard in District 12. The majority of the district is not located in karst-prone areas. Only a thin band along Pine Mountain in Letcher County and Pike County has the potential for karst formation. District 12 has 5 miles of NHS highway that intersect this area of high karst potential, this being sections of US 119 and US 23 in Letcher County.

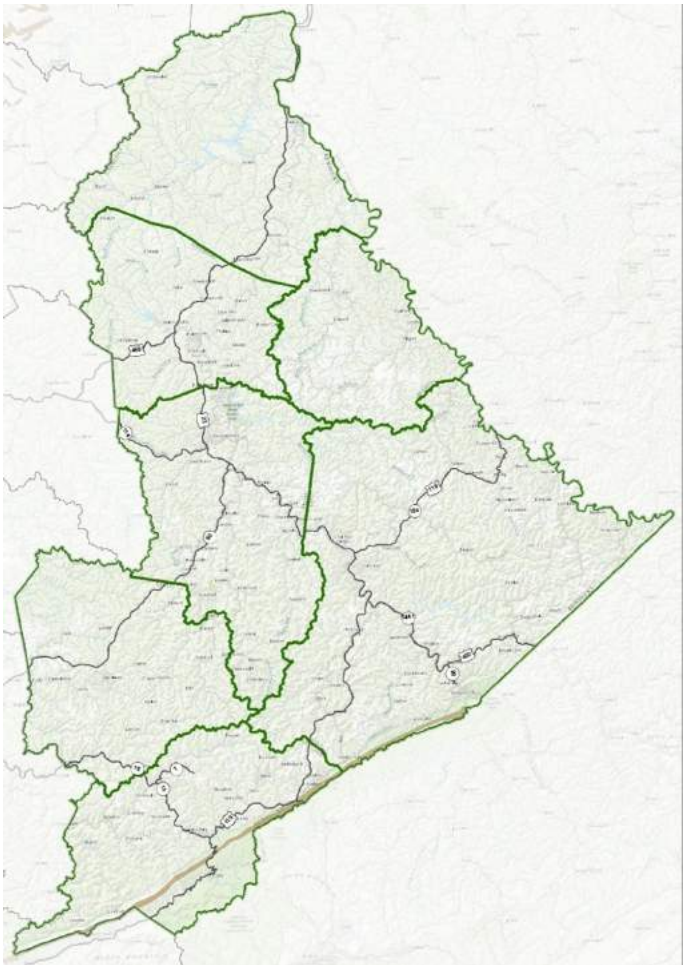


Figure 12-5. Karst potential and sinkholes in KYTC District 12

12.2.5. Other Meteorological Hazards

- Snow/Ice: District 12 annual snowfall averages vary considerably from north to south. Northern areas of the district, including Johnson County and Lawrence County, average

12” to 14” of snowfall annually, which is above the state average. Annual snowfall increases moving southward through the district, with Letcher County and southern Pike County averaging greater than 20” annual snowfall. These totals along the Virginia border in Letcher County and Pike County are highest in the state.

- Freeze/thaw: District 12 counties average between 85 and 104 annual freeze/thaw days. Given the topography of the region, the actual number of freeze/thaw days in a county likely varies depending on the elevation temperature gauges are located.
- Extreme heat: District 12 counties average 1-2 days annually where the temperature exceeds 95 degrees Fahrenheit, compared to the statewide average of 4 such days annually. These are among the lowest in the state.
- Drought/wildfire: Wildfires are more common in District 12 compared to the rest of the state. For the years 2002 to 2016, the district averaged nearly 20 documented wildfires each year. While most of these were small and their impacts minimal, several were significant. In 2016, a wildfire on Pine Mountain in Letcher County along the Virginia border burned over two thousand acres. In 2012, a wildfire on Pine Mountain along the Virginia border at Pike County burned 824 acres. Both of these larger wildfires occurred in wooded areas with minimal population. NHS assets were not impacted.
- Tornado: Compared to other districts in the state, District 12 has above average vulnerability to tornadoes. Tornado vulnerability is fairly even throughout the district, as all ten counties have experienced at least one F3 or above tornado since 1950. From 1950 to 2015, District 12 had 64 tornadoes overall, and 15 of intensity F3 and above tornadoes.

12.3. Workshop

The research team conducted a facilitated workshop in District 12 in August 2017. Eleven KYTC personnel attended the workshop. During the three hour workshop, data was collected from participants through a series of facilitated events, including; a) two keypad exercises where participants were asked to score the criticality of the roadway and the potential impacts of an extreme weather and/or natural hazard event, b) a mapping exercise with a focused conversation to contextualize flooding events in the District, and c) a consensus workshop where participants identified and discussed challenges to performing transportation system maintenance.

12.3.1. Polling Results

For workshop mapping exercises, the NHS was divided into 20 functional roadway segments based upon road designation and county location. Workshop participants were provided with keypads and asked to evaluate each of the NHS segments for criticality and potential impacts from extreme weather and natural hazards. An overall vulnerability score for each segment was computed by multiplying together the criticality and impacts ratings. The vulnerability score, then, provided a metric for identifying the most important highway segments that could potentially suffer the most damage from natural hazards. Table 12-2 illustrates the results of the workshop keypad assessments. The final column ranks each segment by the vulnerability score.

Table 12-2. District 12 workshop polling results showing criticality, impacts, and vulnerability

Segment ID	Segment Description	Criticality	Impacts	Vulnerability	Rank
1	US 23: Lawrence County	8.2	6.6	54.0	11
2	US 23: Johnson County	8.4	6.4	53.5	12
3	US 460: Johnson County	7.1	6.2	43.8	15
4	KY 114: Floyd County	8.3	7.5	62.4	8
5	US 23: Floyd County	8.7	8.2	71.4	2
6	From US 23 South to Ivel Coal Tipple Entrance	3.8	2.2	8.3	20
7	KY 80: Floyd County	7.7	8.0	61.8	9.5
8	KY 80: Knott County	8.0	7.7	61.8	9.5
9	KY 15: Knott County	7.4	7.2	52.9	13
10	KY 7/KY 931: Golden Oak coal tipple connector	5.5	3.2	17.4	16
11	KY 15: Letcher County	7.7	6.7	52.0	14
12	US 119: Letcher County	8.5	8.2	69.9	4
13	US 23: Letcher County	8.5	8.1	69.1	5
14	US 23: Pike County from CR 1267Y to Letcher County line	8.6	8.2	70.7	3
15	US 23: Pike County from CR 1267Y to Floyd County line	8.8	8.5	75.4	1
16	US 119: Pike County	8.5	8.0	67.6	6
17	KY 194: Bevins Branch Prep Plant connector	4.5	2.9	13.0	17
18	US 460: Pike County	7.9	8.3	65.4	7
19	KY 1441/KY 1789: CCI-Energy Slones Branch Terminal connector	3.8	2.4	9.0	19
20	From US 460 to CR 1613A (Cedar Hill Road)	3.3	3.0	9.8	18

12.3.2. Map Exercise

Workshop participants were asked to review and mark-up eight detailed maps of the NHS in District 12. The maps included NHS roadway segments and the associated bridges, culverts, and other structures; other state highways; streams, rivers, and other bodies of water; and the 100-year floodplain. Participants were asked to mark the maps and provide as much detail as possible for areas along the NHS that have A) flooded in the past, B) have been close to flooding in the past, and C) are likely to flood during an extreme weather event. Table 12-3 displays the results of this exercise.

Table 12-3. District 12 NHS segments and flood

District	County	MP	Route	Hazard	Intersecting feature
12	Lawrence	6.18	US-23	Has nearly flooded	confluence R Gorges/Gorges Creek
12	Johnson	0	US-23	Has flooded	by junction with KY-1750
12	Floyd	5.65	US-23	Has flooded	Levisa Fork/Tom's Creek
12	Floyd	0	US-23	Has flooded	Border with Johnson MP0
12	Floyd	6.75	US-23	Has flooded	Levisa Fork near Ivy Creek
12	Pike	26.9	US-23	Has nearly flooded	Tollage Creek/Levisa Fork

12.3.3. Workshop Discussion

Similar to the other eastern Kentucky districts, District 12 is vulnerable to flash flooding and landslides. Because of the topography, roads are generally located in valleys, which is where impacts from flash flooding can be the greatest. Because of this, district personnel stated that pretty much all roads in the district are vulnerable if the precipitation is heavy enough.

In 2015, Flat Gap in Johnson County experienced a devastating flash flood after 5 to 6 inches of rain fell over the area. Four people were killed in the flood and hundreds of homes were damaged or destroyed. District personnel described the flood as a wall of water from hillside to hillside that moved down KY 72. Damage to the transportation system included a bridge on KY 1559 being critically damaged and a bridge on KY 689 being damaged by a house hitting it. A similar type of flash flood hit Pike County in 2010, resulting in two fatalities. During this event, three to seven inches of rain fell over parts of Pike County, with Raccoon Creek being hit the hardest. Multiple homes and vehicles were damaged in the flood.

Flash flooding can result in communities being cutoff as road are flooded. District personnel recalled two occasions where Levisa Fork flooded over US 23, resulting in the town of Ivel being cutoff – sometimes for several days.

12.3.4. Roadways outside of the NHS that flood

District personnel identified multiple roads off the NHS that routinely flood. These include:

- Floyd County – KY 194 at Johns Creek
- KY 1428 east of Prestonsburg
- KY 1210 and KY 122 south of Martin

- KY 122 near Melvin
- Johnson County — KY 581 and KY 80 at the railroad overpass
- US 23 at KY 1750
- Letcher County — KY 313 and KY 343 both flood and have erosion problems
- Martin County — KY 292 near Warfield
- KY 40 south of Inez
- Pike County — KY 1460 south of Pikeville
- KY 319 just south of US 119
- KY 1056 near Tug Fork
- KY 1499 near KY 194
- KY 3227 at US 23

12.3.5. Maintenance facilities flooding

The KYTC maintenance facilities in Johnson County were affected by the 2015 floods.

12.3.6. Consensus workshop

After the discussion of flooding in District 12, participants engaged in a consensus workshop where the following question was posed "What are the Biggest Challenges to Conducting Maintenance in District 12?" Participants were asked to individually brainstorm, then discuss their brainstorm ideas with a partner, and share their ideas with the entire group. Table 12-4 shows the final results from the consensus workshop.

Table 12-4. Results of District 12 consensus workshop

Identified Challenges to Conducting Maintenance Operations in District 12						
Public Response vs. General Maintenance	**Cross Training and Higher Quality Personnel**	**Challenging Locations**	**Construction vs. Maintenance**	**Funding**	**Utility Demands**	**Who has Ownership/Control of Equipment**
Demands of Elected Officials	Personnel -training -absenteeism	Terrain	Putting out fires	No Funding	Dealing with 811	Equipment -Type -Breakdowns
Public Expectations	Program for quick Bridge Repair	Extreme Weather	More focus on Maintenance Management	Need More Flexibility to Determine where Money goes	Utilities	Cannot get parts for Equipment
More Timely Response	Need Better Ownership by Supervisors		Being more Efficient	More Funding	811	Buying wrong types of Equipment
			Illegal Entrances	Money	System is inefficient	Equipment
			Need Routine Maintenance	Funding	Utility lines are too shallow	Need Better Access
				Not Enough Funding	Too many demands	Need a Faster Parts Process

12.4. Results

12.4.1. Identification of most vulnerable assets

Table 12-5 lists District 12 NHS assets with a vulnerability score of 3.5 or greater for any of the four major hazards in this analysis (a full list of District 12 NHS assets and vulnerability scores is in Appendix 2). Landslide is the one hazard that causes the greatest vulnerability in District 12, with US-23 in Floyd County having the highest vulnerability score. Nearly all District 12 NHS segments have high vulnerability to landslide, with a few notable exceptions, including US-460 in Johnson County, KY-15 in Letcher County, and US-23 in Letcher County.

Table 12-5. District 12 NHS assets with vulnerability score 3.5 or greater

District	County	Route	Vulnerability Score	Hazard
12	Knott	KY 15	**3.53**	Landslide
12	Johnson	US 23	**3.60**	Landslide
12	Knott	KY 80	**3.60**	Landslide
12	Lawrence	US 23	**3.60**	Landslide
12	Letcher	US 119	**3.62**	Landslide
12	Pike	US 23	**3.62**	Landslide
12	Pike	US 460	**3.62**	Landslide
12	Floyd	KY 114	**3.68**	Landslide
12	Floyd	KY 80	**3.68**	Landslide
12	Pike	US 119	**3.77**	Landslide
12	Pike	US 23	**3.78**	Landslide
12	Floyd	US 23	**3.83**	Landslide

12.4.2. Worst case scenario

District 12 does not have any interstate or parkway lane miles. Several highways on the NHS serve as critical routes in the district, particularly US 23 and US 119. Any flash flooding that knocked out segments of these roads would constitute the worst case scenario. Because the area is so vulnerable to flash flooding, district personnel believed such flooding is a matter of when, not if.

13. References

Blandford, Benjamin, Scott Schurman, Candice Wallace, and Sarah McCormack. "Transportation System Vulnerability and Resilience to Extreme Weather Events and Other Natural Hazards." University of Kentucky, 2016.

Carey, D. I., T. D. Hounshell, and J. D. Kiefer. "Geologic Hazards in Kentucky." Kentucky Geological Survey, 2008. http://kgs.uky.edu/kgsweb/pubs/pubsearch.asp?pubnum=17235&pubLimit=exact&searchtype=pubnumber.

Cruden, D. M. "A Simple Definition of a Landslide." *Bulletin of the International Association of Engineering Geology* 43, no. 1 (1991): 27–29.

Currens, J.C. "Kentucky Is Karst Country! What You Should Know about Sinkholes and Springs." *Kentucky Geological Survey: Information Circular*, Series XII, 4 (2002): 35.

FEMA. "FEMA Flood Map Service Center," 2016. https://msc.fema.gov/portal.

FHWA. Transportation Asset Management Plans, 23 U.S.C. 119(e)(1), MAP-21 § 1106 § (n.d.).

———. "Transportation System Resilience Preparedness and Resilience to Climate Change and Extreme Weather Events." Washington, D.C.: Federal Highway Administration, 2014.

———. "Vulnerability Assessment Scoring Tool (VAST)." Washington, D.C.: Federal Highway Administration, 2017. https://toolkit.climate.gov/tool/vulnerability-assessment-scoring-tool-vast.

Ford, Derek, and Paul Williams. *Karst Hydrogeology and Geomorphology*. West Sussex, England: John Wiley & Sons, Ltd, 2007.

Godt, Jonathan W. "Digital Compilation of Landslide Overview Map of Teh Conterminous United States." United States Geological Survey, 2008. https://landslides.usgs.gov/hazards/nationalmap/.

KGS. "Landslide Hazards in Kentucky." Lexington, KY: Kentucky Geological Survey, 2004. https://www.uky.edu/KGS/geologichazards/landslide_factsheet.pdf.

———. "Water Fact Sheet." Lexington, KY: Kentucky Geological Survey, 2016. https://www.uky.edu/KGS/education/factsheet_water.pdf.

Kunkel, Kenneth E., Laura E. Stevens, Scott E. Stevens, Liqiang Sun, Emily Janssen, Donald Wuebbles, Charles E. Konrad II, et al. "Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 2. Climate of the Southeast U.S." NOAA Technical Report. Washington, DC: National Oceanic and Atmospheric Administration, 2013.

KYEM. “Commonwealth of Kentucky Enhanced Hazard Mitigation Plan.” Kentucky Emergency Management, 2013. http://kyem.ky.gov/recovery/Documents/CK-EHMP%202013,%20Standard%20and%20Enhanced.pdf.

KYTC. “Highway Information System GIS Extracts.” Kentucky Transportation Cabinet, 2017. https://transportation.ky.gov/Planning/Pages/HIS-Extracts.aspx.

Moore, Harry, and Barry Beck. “Karst Terrane and Transportation Issues.” In *Encyclopedia of Sustainability Science and Technology*, edited by Robert A. Meyers, 5645–71. New York, NY: Springer New York, 2012.

Paylor, Randall L., and J.C. Currens. “Karst Occurrence in Kentucky.” Lexington, KY: Kentucky Geological Survey, 2001. http://kgs.uky.edu/kgsweb/olops/pub/kgs/mc33_12.pdf.

Paylor, Randall L., Lee Florea, Michael Caudill, and J.C. Currens. “GIS Sinkhole Database.” Kentucky Geological Survey, 2003.

The National Severe Storms Laboratory. “Floods.” National Oceanic and Atmospheric Administration, 2016. http://www.nssl.noaa.gov/education/svrwx101/floods/.

U.S. Census Bureau, Population Division. “SubCounty Population Estimates: April 1, 2010 to July 1, 2016,” 2017. http://ksdc.louisville.edu/wp-content/uploads/2017/05/subcoest_2016_alpha.xlsx.

USGS. “Earthquake Glossary.” United States Geological Survey, 2016. http://earthquake.usgs.gov/learn/glossary/?term=earthquake.

———. “Landslide Types and Processes.” United States Geological Survey, 2004. http://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html.

———. “PGA 2% in 50 Yrs.” Earthquake Hazards Program. United States Geological Survey, 2014. http://earthquake.usgs.gov/hazards/products/conterminous/.

Wang, Zhenming. “Ground Motion for the Maximum Credible Earthquake in Kentucky.” Series XII. Lexington, KY: Kentucky Geological Survey, 2010.

14. Appendices

14.1. Appendix 1: VAST Data Inputs

Listing and description of the 22 datasets used as input indicators for the VAST analysis. Data for each indicator were reclassified from 1 to 4. The thresholds used for each reclassification are demonstrated in the table below.

Indicator Type	Hazard Type	Description	Measure/Units	1	2	3	4	Source
Exposure	Earthquake	Peak Ground Acceleration	Max PGA zone wherein asset lies	6 to 17	18 to 39	40 to 79	80 to 120	USGS[25]
Exposure	Flood	Historical Precipitation	Historical average annual # of days where precipitation >3"	0 to .11	.11 to .22	.22 to .33	.33 to .51	Data provided by Midwest Regional Climate Center
Exposure	Flood	Projected Precipitation	Future projected average annual # of days where precipitation >1"		7	9	11	Kunkel et al[26]
Exposure	Flood	KGS Flood Hazard layer	Segments intersecting this layer	No			Yes	KGS[27]
Exposure	Flood	Location via 100-yr floodplain	Percent of centerline miles located in floodplain	0	0 to 1	2 to 5	>5	KTC GIS analysis
Exposure	Landslide	USGS Landslide susceptibility	Percent of centerline miles located in high landslide zone	0	0 to 10	10 to 20	>20	USGS[28]
Exposure	Landslide	Max slope	Maximum slope within 200' of centerline	0 to 50	50 to 100	100 to 150	>150	KTC GIS analysis
Exposure	Landslide	Mean slope	Mean slope along NHS segment within 200' of centerline	0 to 5	5 to 10	10 to 15	>15	KTC GIS analysis

[25] USGS, "PGA 2% in 50 Yrs."
[26] Kunkel et al., "Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 2. Climate of the Southeast U.S."
[27] Carey, Hounshell, and Kiefer, "Geologic Hazards in Kentucky."
[28] Godt, "Digital Compilation of Landslide Overview Map of The Conterminous United States."

Indicator Type	Hazard Type	Description	Measure/Units	1	2	3	4	Source
Exposure	Landslide	KGS Slope Stability/Landslide layer	Segments intersecting this layer	No			Yes	KGS[29]
Exposure	Landslide	KGS Landslide Inventory	Landslides within 500' of NHS per centerline mile	0	.1 to .5	.51 to 1.5	>1.5	KGS[30]
Exposure	Sinkhole	KGS Karst Potential	Percent of centerline miles located in high karst zone	0	1 to 33	34 to 66	>66	KGS[31]
Exposure	Sinkhole	KGS Karst Hazard layer	Segments intersecting this layer	No			Yes	KGS[32]
Exposure	Sinkhole	KGS Sinkhole database	Acres of sinkholes per centerline miles	0	.1 to 5	5.1 to 10	>10	KGS[33]
Sensitivity	Flood	Workshop mapping results	NHS segments identified in workshops as having flooded	No			Yes	KYTC district workshops
Sensitivity	Flood	FEMA flood event	NHS segments that experienced FHWA/FEMA response flood events	No			Yes	FHWA/KYTC/FEMA. Data provided by KYTC
Sensitivity	Landslide	Workshop landslide results	NHS segments identified in workshops as having landslides	No			Yes	KYTC district workshops
Sensitivity	Landslide	FEMA slide event	NHS segments that experience FHWA/FEMA response landslide events	No			Yes	FHWA/KYTC/FEMA. Data provided by KYTC
Sensitivity	Sinkhole	Workshop sinkhole results	NHS segments identified in workshops as having sinkholes	No			Yes	KYTC district workshops

[29] Carey, Hounshell, and Kiefer, "Geologic Hazards in Kentucky."
[30] KGS, "Landslide Hazards in Kentucky."
[31] Paylor and Currens, "Karst Occurrence in Kentucky."
[32] Carey, Hounshell, and Kiefer, "Geologic Hazards in Kentucky."
[33] Paylor et al., "GIS Sinkhole Database."

Indicator Type	Hazard Type	Description	Measure/Units	1	2	3	4	Source
Adaptive Capacity	ALL	AADT	Max average annual daily traffic on NHS segment	0 to 8,000	8,001 to 16,000	16,001 to 24,000	>24,000	KYTC Highway Information System (HIS) Database[34]
Adaptive Capacity	ALL	Criticality Rating	Workshop keypad criticality rating of NHS segment	1 to 2.25	2.26 to 4.5	4.56 to 6.75	>6.75	KYTC district workshops
Adaptive Capacity	ALL	Functional Class	Functional classification of NHS segment	7	5,6	3,4	1,2	KYTC HIS
Adaptive Capacity	ALL	Impacts Rating	Workshop keypad impacts rating of NHS segment	1 to 2.25	2.26 to 4.5	4.56 to 6.75	>6.75	KYTC district workshops

[34] KYTC, "Highway Information System GIS Extracts."

14.2. Appendix 2: VAST Results for All NHS Segments

Vulnerability scores on flood, landslide, sinkhole, and earthquake for all KYTC NHS highway segments. Vulnerability scales from 1 to 4, where 4 indicates highest vulnerability.

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
1	1	Ballard	US 51	16.86	3.83	1.89	3.43	2.36
1	2	Ballard	US 60	4.58	3.50	1.67	3.54	2.07
1	3	McCracken	US 60	10.70	3.67	1.78	2.57	1.84
1	4	McCracken	I-24	2.96	3.50	2.00	2.71	2.07
1	5	McCracken	US 45	10.80	3.00	1.67	2.38	2.00
1	6	McCracken	US 60 / US 45X / US 60X	10.92	3.00	1.67	3.37	3.00
1	7	McCracken	US 60 / US 68 / US 62	9.63	3.00	1.67	3.46	2.73
1	8	McCracken	I-24	14.33	3.38	1.92	3.29	3.32
1	9	Graves	US 45	13.37	3.00	1.67	2.63	1.87
1	10	Graves	JC 9003	9.80	3.13	1.75	3.38	2.02
1	11	Fulton/Hickman	JC 9003 / US 51 / CR 1013	8.94	3.13	1.75	3.54	1.88
1	12	Graves	JC 9003	16.42	3.00	1.67	3.54	2.00
1	13	Graves	KY 121 / KY 80	12.89	2.75	1.50	3.13	1.70
1	14	Marshall	I-24	12.03	3.38	1.92	2.88	2.18
1	15	Marshall	JC 9003	16.95	3.25	1.83	2.71	3.23
1	16	Marshall	KY 348 / US 641S / US 641	14.17	3.00	1.67	2.54	2.00
1	17	Calloway	US 641	6.17	2.75	1.50	2.46	1.70
1	18	Calloway	US 641	11.26	3.00	1.67	2.54	1.87
1	19	Calloway/Marshall	KY 80 / US 68	25.54	2.75	1.50	2.46	1.83
1	20	Livingston	I-24	4.50	3.38	1.92	2.88	2.25
1	21	Lyon	I-69	5.64	2.63	2.53	2.21	2.08
1	22	Lyon	I-24	20.97	3.38	2.70	2.71	3.18
1	23	Trigg	US 68	28.12	2.38	2.58	2.54	1.92
1	24	Trigg	I-24	12.48	2.88	3.92	2.54	1.92

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
2	1	Henderson	US 41	10.19	3.00	2.00	3.87	3.33
2	2	Henderson	US 60 / US 41A / KY 351	7.20	2.63	1.75	3.54	1.95
2	3	Henderson	KY 425	4.74	2.38	1.58	3.04	1.78
2	4	Henderson	AU 9005	15.87	2.75	1.83	3.54	3.30
2	5	Henderson	I-69	10.95	2.63	1.75	3.54	2.02
2	6	Daviess	US 231	3.56	2.25	1.50	3.04	1.50
2	7	Daviess	US 60	17.55	2.88	1.92	3.46	2.18
2	8	Daviess	CS 1060 / KY 331	2.44	2.25	1.50	2.29	1.77
2	9	Daviess	KY 2262	1.51	2.63	1.75	2.38	1.75
2	10	Daviess	AU 9005	7.60	2.75	1.83	3.71	3.17
2	11	Daviess	KY 81 / KY 54	5.16	2.38	1.58	3.21	1.78
2	12	Daviess	KY 2155	3.73	2.38	1.58	3.21	1.78
2	13	Daviess	KY 2831	2.56	2.38	1.58	3.21	1.58
2	14	Daviess	WN 9007	10.75	2.63	1.75	3.63	2.02
2	15	Webster	I-69	10.31	2.75	1.83	2.63	2.23
2	16	Ohio	WN 9007	24.35	2.63	2.08	2.46	3.22
2	17	Ohio	WK 9001	21.94	2.25	1.83	2.63	3.37
2	18	Hopkins	I-69	15.26	2.75	1.83	3.71	2.17
2	19	Muhlenberg/Hopkins	WK 9001 / I-69	27.37	2.75	1.83	2.63	3.23
2	20	Hopkins	I-69	21.79	2.75	1.83	2.63	3.30
2	21	Caldwell	I-69	16.18	2.75	3.72	3.62	3.30
2	22	Christian/Hopkins	EB 9004	22.60	2.88	2.47	2.79	2.25
2	23	Christian	US 41 / US 68	21.10	2.50	2.56	3.37	1.67
2	24	Christian	US 68B	11.05	2.50	3.56	3.29	1.67
2	25	Christian	I-24	23.48	3.00	4.00	3.54	3.13
2	26	Christian	US 41A	16.00	2.75	3.83	3.46	1.83
2	27	Christian	EB 9004	11.79	2.88	3.92	3.62	2.05
2	28	Caldwell	I-24	2.56	2.88	2.70	2.46	1.92

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
3	1	Butler	WK 9001 / WN 9007	17.82	2.13	2.08	2.63	3.22
3	2	Barren/Edmonson	I-65	11.07	2.50	4.00	2.46	2.13
3	3	Barren	LN 9008	8.72	2.25	2.61	2.38	2.17
3	4	Barren	LN 9008	13.65	2.25	2.50	2.38	3.23
3	5	Metcalfe	LN 9008	13.81	2.13	2.53	2.29	3.28
3	6	Warren	WN 9007	10.72	2.25	2.50	2.54	3.10
3	7	Warren	US 68 / US 31W / KY 446	10.75	2.38	2.81	2.88	1.98
3	8	Warren	I-65	14.91	2.50	4.00	2.46	2.13
3	9	Warren	I-65	14.33	2.50	4.00	2.79	2.07
3	10	Warren	US 68	8.22	2.13	3.75	2.38	1.75
3	11	Warren	WN 9007	9.53	2.38	3.92	2.46	1.92
3	12	Warren	US 231	13.92	2.13	3.75	3.54	1.88
3	13	Logan	US 68	15.09	1.88	2.58	2.54	1.58
3	14	Logan	US 68	14.09	1.88	2.36	2.29	1.58
3	15	Logan	US 431 / US 79	11.70	1.75	2.28	3.21	1.50
3	16	Todd	US 68	14.36	2.25	2.28	2.13	1.50
3	17	Todd	US 79	10.59	2.25	3.50	2.21	1.50
3	18	Simpson	I-65	13.76	2.50	4.00	2.63	2.13
3	19	Allen	US 231	8.56	1.88	2.25	2.13	1.85
3	20	Allen	US 31E	8.60	1.88	2.03	3.29	1.98
3	21	Warren	KY 880 / KY 234	3.39	2.13	2.75	2.21	1.75
4	1	Grayson	WK 9001	31.30	2.13	2.19	2.63	3.28
4	2	Hardin	US 31W	4.12	2.00	2.22	3.63	1.80
4	3	Meade	US 31W	3.53	2.00	2.67	2.04	2.00
4	4	Hardin	US 31W	8.83	2.00	3.67	2.13	1.67
4	5	Hardin	US 31W	5.61	2.00	2.67	2.29	1.67
4	6	Hardin	US 31WB	3.53	1.88	3.36	2.21	1.65
4	7	Hardin	KY 313	9.49	1.63	1.97	3.38	3.02

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
4	8	Hardin	I-65	12.21	2.50	3.67	2.96	2.53
4	9	Hardin	WK 9001	17.37	2.25	3.72	2.63	1.97
4	10	Hardin	BG 9002	8.82	2.13	2.31	2.71	2.22
4	11	Hardin	I-65	12.37	2.50	3.89	3.87	2.07
4	12	Larue	I-65	4.05	2.50	4.00	2.37	2.13
4	13	Hart	I-65	20.76	2.50	4.00	2.88	2.40
4	14	Nelson	BG 9002	30.48	2.13	2.19	2.54	3.15
4	15	Washington	BG 9002	5.49	2.13	1.75	2.21	2.22
4	16	Washington	KY 555 / KY 55	19.28	1.75	1.83	2.04	1.90
4	17	Marion	KY 2154 / KY 55	6.06	1.75	1.94	2.13	1.77
4	18	Marion	US 68	9.35	1.75	1.83	3.38	1.83
4	19	Taylor	US 68	8.69	2.00	2.11	2.13	1.93
4	20	Taylor	KY 55	10.27	1.88	2.14	2.29	1.92
5	1	Jefferson	I-64	6.14	2.25	1.94	3.46	2.17
5	2	Jefferson	I-64	12.65	2.25	2.28	3.29	2.17
5	3	Jefferson	I-64	5.17	2.13	2.19	2.13	2.08
5	4	Jefferson	I-65	0.00	1.75	1.50	3.04	1.57
5	5	Jefferson	I-65	1.51	2.13	1.75	3.29	1.88
5	6	Jefferson	I-65	6.42	2.13	1.97	3.29	1.95
5	7	Jefferson	I-65	6.23	2.25	1.94	2.54	3.10
5	8	Jefferson	I-71	11.25	2.25	2.28	2.54	2.23
5	9	Jefferson	I-264	12.66	2.13	1.86	3.46	2.02
5	10	Jefferson	I-264	10.24	2.25	3.28	2.21	2.03
5	11	Jefferson	KY 841	10.23	2.38	1.92	2.54	3.32
5	12	Jefferson	I-265	24.46	2.25	2.50	2.12	3.37
5	13	Jefferson	KY 841	4.15	2.00	2.11	2.21	1.93
5	14	Jefferson	US 31	1.12	1.75	1.50	3.04	1.50

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
5	15	Jefferson	CS 1124A / KY 1020 / CS 1036A / CS 1014B / CS 1009B / CS 1006F	1.09	1.88	1.58	3.38	1.58
5	16	Jefferson	CS 1011F / CS 1009A / CS 1004A / CS 1049F / CS 1046A	1.32	1.75	1.50	2.04	1.50
5	17	Jefferson	US 150T / US 150 / US 31W	26.72	2.13	1.75	3.54	2.02
5	18	Jefferson	CR 1020G / US 31E	14.28	2.00	2.00	2.38	1.87
5	19	Jefferson	US 42	9.95	2.00	2.11	3.37	2.00
5	20	Jefferson	CS 1021F / US 150	4.43	1.88	1.69	2.38	1.78
5	21	Jefferson	KY 2056 / KY 2051 / KY 1934 / CR 1012F / CR 1002F	15.65	2.25	1.83	2.63	1.90
5	22	Jefferson	KY 1865	5.02	2.00	1.67	2.29	1.87
5	23	Jefferson	CR 1001G	1.04	2.00	1.67	2.21	1.87
5	24	Jefferson	KY 1703 / CR 1016G / CR 1010G	1.13	2.13	2.08	2.29	1.95
5	25	Jefferson	KY 22 / KY 1747	18.06	2.00	2.11	2.38	1.87
5	26	Jefferson	KY 155	10.52	1.88	1.92	1.96	1.85
5	27	Jefferson	US 60	12.16	2.13	2.08	2.13	1.95
5	28	Jefferson	KY 1447	4.75	1.88	2.03	2.04	1.78
5	29	Jefferson	KY 913	4.35	2.00	1.89	1.96	1.93
5	30	Oldham	I-71	13.52	2.25	2.06	2.29	2.23
5	31	Henry/Trimble	I-71	14.02	2.13	2.08	2.21	3.28
5	32	Shelby	I-64	22.33	2.25	2.28	3.29	3.23
5	33	Franklin	I-64	13.14	2.38	2.58	2.54	3.45
5	34	Franklin	US 127	10.93	1.88	2.25	2.29	3.12
5	35	Franklin	US 421 / US 60	4.81	2.25	2.83	2.46	1.97
5	36	Franklin	KY 676	5.28	1.75	2.28	2.13	2.97
5	37	Bullitt	I-65	19.91	2.38	2.03	2.63	3.32
6	1	Carroll	I-71	14.64	2.38	2.36	3.62	3.52

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
6	2	Gallatin	I-71	16.43	2.38	2.25	2.46	3.52
6	3	Boone	I-71	7.83	2.38	2.25	2.29	3.45
6	4	Grant	I-75	23.04	2.38	2.25	2.87	3.45
6	5	Boone/Kenton	I-75	5.05	2.38	2.36	2.21	3.25
6	6	Boone/Kenton	I-75	12.09	2.38	2.25	3.46	3.32
6	7	Kenton	I-75	6.73	2.50	2.33	3.54	3.73
6	8	Kenton	I-75	1.57	2.50	2.00	3.54	3.53
6	9	Boone	I-275	6.85	2.38	2.25	2.21	3.72
6	10	Boone/Kenton	I-275	7.05	2.38	2.25	2.54	3.65
6	11	Kenton/Campbell	I-275	6.23	2.50	2.33	2.54	3.73
6	12	Campbell	I-275	4.53	2.50	2.33	3.54	3.80
6	13	Campbell	CS 1006 / I-471	4.83	2.50	2.33	3.54	3.80
6	14	Campbell	I-471 / KY 471	0.96	2.50	2.00	3.71	2.33
6	15	Boone	KY 237	8.98	2.13	2.08	2.38	2.15
6	16	Boone	US 42	1.47	2.13	2.08	2.04	2.08
6	17	Boone	KY 18	3.30	2.13	2.08	2.38	3.15
6	18	Boone	KY 212	0.83	2.13	1.75	2.29	2.22
6	19	Kenton/Campbell	KY 8	3.78	2.00	1.67	3.21	1.93
6	20	Kenton/Campbell	KY 1120	3.42	2.00	1.67	2.21	3.00
6	21	Kenton	KY 17	0.39	1.88	1.58	2.13	1.78
6	22	Kenton	KY 17	6.91	2.13	1.75	2.96	2.28
6	23	Campbell	US 27	0.55	1.88	1.58	2.04	1.78
6	24	Campbell	US 27	3.49	1.88	1.92	3.04	3.12
6	25	Kenton	KY 16	2.87	2.00	2.00	2.96	2.33
6	26	Campbell	US 27	3.05	2.25	2.17	2.04	2.43
6	27	Campbell	KY 9	17.88	2.25	2.17	2.29	3.63
6	28	Pendleton	KY 9	4.33	1.75	1.83	1.71	2.10
6	29	Bracken	KY 9	19.80	1.75	1.83	1.79	3.17

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
6	30	Robertson	US 68	1.34	1.63	1.86	1.63	1.88
7	1	Anderson	US 127 / US 127B	11.36	1.88	2.25	1.96	1.92
7	2	Anderson/Mercer	BG 9002	17.18	2.25	2.39	2.21	2.37
7	3	Mercer	US 127 / US 127B	18.09	1.88	2.36	2.04	1.85
7	4	Boyle	US 127 / US 127B	10.98	1.88	2.36	2.04	1.78
7	5	Boyle	US 150 / US 150B	4.33	1.75	1.94	1.88	2.83
7	6	Woodford/Scott/Fayette	I-64	15.38	2.38	2.81	2.29	2.05
7	7	Woodford	US 60	13.03	2.00	2.45	2.04	1.93
7	8	Woodford	BG 9002	9.21	2.25	2.61	2.21	1.97
7	9	Scott	KY 3487 / KY 620 / US 62	8.48	2.00	2.45	1.96	3.00
7	10	Scott/Fayette	KY 1973 / US 25	3.29	1.88	2.25	2.13	1.58
7	11	Scott	I-75	18.38	2.38	2.58	2.21	3.45
7	12	Scott/Fayette	I-75	7.44	2.50	2.78	3.37	2.07
7	13	Fayette	I-75	13.55	2.38	2.70	2.29	3.32
7	14	Fayette	I-75	6.19	2.50	2.78	2.29	2.33
7	15	Fayette	I-64	8.40	2.38	2.58	2.21	2.05
7	16	Fayette	KY 4	13.80	2.25	2.61	2.21	2.17
7	17	Fayette	KY 4	5.51	2.13	2.42	3.21	1.95
7	18	Fayette	KY 922	3.39	2.13	2.53	2.21	1.75
7	19	Fayette	KY 1681 / US 421	2.10	1.88	2.25	1.88	1.58
7	20	Fayette	US 60	8.67	2.13	2.53	2.13	1.88
7	21	Fayette	US 68	4.56	2.00	2.45	1.96	1.67
7	22	Fayette	CS 4745 / US 27 / CS 7087	11.83	2.13	2.53	3.21	1.75
7	23	Fayette	KY 1974	4.26	2.00	2.45	2.21	1.87
7	24	Fayette	KY 418 / US 25	10.44	2.13	2.53	2.04	1.95
7	25	Fayette	US 60	3.92	2.00	2.45	2.04	1.87
7	26	Fayette	US 27	5.20	2.00	2.45	2.13	1.67

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
7	27	Fayette	CS 4909 / CS 4907 / CS 3288 / CS 3286	2.45	1.75	2.17	1.79	1.50
7	28	Fayette	CS 3016 / CS 4524	15.79	2.13	2.53	2.13	2.02
7	29	Jessamine	US 27	9.98	2.25	2.61	2.21	1.90
7	30	Jessamine	US 27	5.38	2.00	2.67	1.96	2.93
7	31	Garrard	US 27	16.66	2.00	2.33	2.13	3.07
7	32	Bourbon	US 68	10.75	1.75	2.17	2.04	2.63
7	33	Bourbon	US 27	8.76	1.88	2.36	2.04	1.65
7	34	Clark	I-64	14.79	2.25	2.50	2.12	2.17
7	35	Clark/Madison	KY 627 / KY 1958	15.14	2.13	2.42	3.12	2.22
7	36	Clark	KY 9000	11.90	2.13	2.19	2.13	3.15
7	37	Madison	I-75	24.35	2.50	2.44	3.29	3.80
7	38	Madison	US 25 / KY 876	7.74	2.00	2.11	1.96	1.93
7	39	Madison	US 421 / US 25 / KY 2872	5.22	1.88	2.03	1.79	1.78
7	40	Montgomery	I-64	11.43	2.38	2.25	2.29	3.52
8	1	Lincoln	US 127	10.66	2.00	2.11	2.13	2.07
8	2	Lincoln	US 150	5.47	1.88	1.92	3.04	1.92
8	3	Lincoln	US 27	21.91	2.13	2.31	3.21	3.22
8	4	Rockcastle	I-75	22.60	2.50	2.56	3.71	3.87
8	5	Rockcastle	US 25 / KY 461	10.21	2.00	2.45	2.13	2.27
8	6	Casey	US 127	23.92	2.13	2.08	3.63	3.28
8	7	Adair	KY 55X / KY 55	12.03	1.75	2.28	1.96	1.83
8	8	Adair	LN 9008	21.62	2.00	3.33	2.04	2.07
8	9	Russell	US 127	26.24	2.13	2.31	2.46	3.35
8	10	Russell	LN 9008	14.32	1.88	2.03	2.04	3.18
8	11	Pulaski	LN 9008	16.28	2.00	2.22	2.13	3.27
8	12	Pulaski	US 27	7.55	1.88	2.14	2.21	3.12
8	13	Pulaski	US 27	23.28	2.25	3.72	3.54	3.57

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
8	14	Pulaski	KY 80	20.80	2.13	2.53	2.54	3.42
8	15	Pulaski	KY 461	8.49	1.88	2.36	2.04	2.18
8	16	Pulaski	KY 914	13.33	1.88	3.58	3.04	1.92
8	17	Clinton	US 127	21.57	1.75	2.50	2.04	1.97
8	18	McCreary	US 27	22.28	1.88	1.58	2.29	2.32
9	1	Nicholas	US 68	12.13	1.63	2.08	1.88	1.82
9	2	Fleming	US 68	5.41	1.63	1.75	1.71	2.82
9	3	Mason	US 68	14.32	1.75	1.94	1.79	1.77
9	4	Mason	US 68	4.20	2.00	2.00	2.21	3.33
9	5	Mason	KY 9	19.56	2.00	2.11	1.96	3.07
9	6	Lewis	KY 9	31.02	1.75	1.61	3.04	3.03
9	7	Lewis	KY 10	12.97	1.75	1.50	2.62	3.10
9	8	Greenup	KY 10	11.60	1.63	1.42	1.88	1.88
9	9	Greenup	KY 10	1.21	1.88	1.58	2.21	1.65
9	10	Greenup	KY 8S / KY 8	1.66	1.88	1.58	1.96	3.05
9	11	Greenup	US 23	12.92	2.00	1.67	3.12	3.07
9	12	Greenup	US 23	15.92	2.25	1.83	3.37	3.70
9	13	Bath	I-64	13.32	2.25	1.83	3.12	3.37
9	14	Rowan	I-64	19.71	2.25	2.28	3.46	3.63
9	15	Carter	I-64	32.15	2.38	2.47	2.54	3.72
9	16	Carter	KY 9 / KY 1	18.76	1.63	1.53	2.04	2.08
9	17	Boyd	I-64	10.03	2.50	2.00	2.46	3.87
9	18	Boyd	I-64	0.57	2.38	1.92	2.29	2.45
9	19	Boyd	US 60 / KY 180	10.79	2.13	1.75	3.37	2.35
9	20	Boyd	US 60 / US 23S / CS 2551	1.11	2.13	1.75	2.29	3.28
9	21	Boyd	US 23 / US 23X	21.21	2.25	1.83	2.38	2.63
9	22	Boyd	KY 757	2.27	1.25	1.17	1.54	2.70
10	1	Powell	KY 9000	24.06	2.13	1.86	3.46	2.55

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
10	2	Wolfe	KY 9000	6.86	2.00	1.67	1.96	3.53
10	3	Wolfe	KY 9009 / KY 9000	14.80	2.00	1.67	3.21	3.67
10	4	Wolfe	KY 15S / KY 15	10.57	1.88	1.58	2.79	2.52
10	5	Morgan	KY 9009	5.39	2.00	1.67	3.21	2.60
10	6	Magoffin	KY 9009	12.56	1.88	1.58	3.04	3.58
10	7	Magoffin	US 460	7.85	2.00	1.67	2.04	3.60
10	8	Magoffin	KY 114	5.02	1.88	1.58	1.96	3.58
10	9	Breathitt	KY 15	25.62	2.00	1.67	3.21	3.67
10	10	Perry	KY 15	8.66	2.00	1.67	2.21	3.67
10	11	Perry	KY 15	16.57	2.25	1.83	2.46	2.83
10	12	Perry	HR 9006	8.09	2.13	1.75	2.29	3.75
10	13	Perry	KY 80	7.94	2.00	1.67	2.13	3.53
11	1	Laurel	I-75	22.85	2.50	3.44	2.63	3.67
11	2	Laurel	KY 80	11.26	2.13	2.19	2.29	2.22
11	3	Laurel	HR 9006	10.60	2.00	1.67	2.29	2.33
11	4	Laurel	KY 192	3.81	2.13	1.75	2.38	2.02
11	5	Clay	HR 9006	25.35	2.00	1.67	2.38	2.60
11	6	Leslie	HR 9006	15.08	1.88	1.58	2.29	2.45
11	7	Whitley	I-75	27.95	3.00	2.00	3.79	3.87
11	8	Whitley	US 25W / KY 3041	2.61	1.88	1.58	2.13	2.25
11	9	Knox	KY 3041	3.89	1.75	1.50	2.04	2.10
11	10	Laurel	US 25E	2.05	2.25	1.83	2.46	2.17
11	11	Knox	US 25E	26.25	2.75	1.83	3.46	3.57
11	12	Bell	US 25E	18.60	2.63	2.19	3.37	3.68
11	13	Bell	US 119	15.88	2.63	1.75	2.54	3.68
11	14	Harlan	US 119	39.05	2.63	1.75	3.29	3.68
12	1	Lawrence	US 23	29.00	2.00	1.67	3.21	3.60
12	2	Johnson	US 23	16.87	2.00	1.67	3.12	3.60

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
12	3	Johnson	US 460	7.83	1.88	1.58	2.04	2.52
12	4	Floyd	KY 114	11.32	2.13	1.75	2.96	3.68
12	5	Floyd	US 23	22.00	2.25	1.83	3.29	3.83
12	6	Floyd	CR 1659	0.21	1.13	1.08	1.38	1.68
12	7	Floyd	KY 80	14.36	2.13	1.75	2.29	3.68
12	8	Knott	KY 80	20.09	2.00	1.67	2.04	3.60
12	9	Knott	KY 15	9.31	2.00	1.67	2.13	3.53
12	10	Letcher	KY 931 / KY 7	6.81	1.75	1.50	2.13	2.23
12	11	Letcher	KY 15	10.65	2.00	1.67	2.13	2.47
12	12	Letcher	US 119	27.86	2.13	2.19	3.37	3.62
12	13	Letcher	US 23	7.28	2.13	2.19	2.13	2.55
12	14	Pike	US 23	18.11	2.13	1.75	2.29	3.62
12	15	Pike	US 23	14.52	2.38	1.92	3.12	3.78
12	16	Pike	US 119	25.60	2.25	1.83	2.38	3.77
12	17	Pike	KY 194	1.06	1.50	1.33	1.71	2.27
12	18	Pike	US 460	25.26	2.13	1.75	3.29	3.62
12	19	Pike	KY 1789 / KY 1441	1.30	1.38	1.25	1.79	2.18
12	20	Pike	KY 80	2.12	1.38	1.25	1.63	3.05

MEMO

TO: Tracy Nowaczyk (KYTC)

FROM: Elizabeth Farc (WSP), Chris Dorney (WSP), and Mike Meyer (independent consultant)

SUBJECT: Task 1.2 Memo: Review of KYTC Resilience Efforts to Date

DATE: July 30, 2024

INTRODUCTION

This memorandum summarizes the resilience-related activities and studies the Kentucky Transportation Cabinet (KYTC) has undertaken during the past eight years; the period over which the topic of resilience became a more explicit policy concern at the agency. The information for this summary came from a review of documents provided by KYTC, an interview with Dr. Benjamin Blandford of the Kentucky Transportation Center (KTC, who has been heavily involved in many of the resilience research projects), and an interview with KYTC staff including some who have participated in recent disaster recovery efforts. The next section describes the KYTC experience with recent major disasters including lessons learned and action items for improvement. After this, additional resilience activities noted at meetings with the KYTC Executive Team, Project Delivery/Preservation Directors, and Project Development Directors are discussed. Subsequently, the key findings from the resilience efforts undertaken thus far are summarized, and several recommendations are provided for KYTC to consider in order to begin addressing the identified gaps.

REVIEW OF KYTC STUDIES AND PLANS

Much of the resilience work sponsored by the KYTC has focused on studies undertaken by the KTC. Each of the studies described below focused on particular asset-hazard combinations (e.g., flooding and bridges) considered of greatest concern to Kentucky. These studies have, in most cases, followed logically from one to the next and thus represent an evolution in the KYTC approach toward understanding transportation system resilience challenges facing the Commonwealth. The vulnerability studies have subsequently been used to inform plans like the Long-Range Statewide Transportation Plan and the Resilience Improvement Plan (RIP). The summaries of each study/plan are arranged chronologically with the earliest study, the vulnerability assessment pilot project in District 1, described first and the latest effort, the Commonwealth's Resilience Improvement Plan (RIP), described last.

TRANSPORTATION SYSTEM VULNERABILITY AND RESILIENCE TO EXTREME WEATHER EVENTS AND OTHER NATURAL HAZARDS, PILOT PROJECT — KYTC DISTRICT 1 (2016):[1]

This study provided an overview of vulnerability assessments and documented natural hazards that will likely be prevalent in the future along the National Highway System (NHS) in Kentucky. The study culminated in a vulnerability assessment of the NHS within KYTC's District 1 (in western Kentucky).

[1] Blandford, B., S. Schurman, C. Wallace, and S. M. McCormack. 2016. Transportation System Vulnerability and Resilience to Extreme Weather Events and Other Natural Hazards: Report for Pilot Project — KYTC District 1, Report KTC-16-20/SPR16-524-1F, Frankfurt, KY: KYTC. Accessed April 18, 2024 from https://uknowledge.uky.edu/ktc_researchreports/1554/

The analysis of meteorological and asset data was supplemented by workshops with District staff to augment the analysis with local knowledge on past experience with highway disruptions.

The initial set of hazards considered included flooding, tornados, wind, hail, winter storms, extreme heat, drought, wildfire, fog, and freeze/thaw cycles, earthquakes, landslides, and sinkholes. Historical data on each of these hazards was gathered for the state. Next, county-level historical meteorological data were used to identify trends in key stressor values (e.g., heavy precipitation, extreme temperatures, etc.) statewide, although the historical data were only available from 1980, thus limiting the degree of establishing long-term trends. Future climate projections for temperature and precipitation in Kentucky were then summarized. A survey of KYTC officials at the Central Office and in other districts was then used to identify the most important hazards for more detailed analysis, identified as: earthquakes, flooding, landslides, and sinkholes. These hazards were the focus of the District 1 pilot study.

The District 1 study utilized seismic data from the United States Geological Survey (USGS) augmented with prior more detailed seismic studies of KYTC bridges and embankments. Flooding was assessed by overlaying NHS roadways, bridges, large culverts, and structures (overpasses) with the FEMA 100-year floodplain (derived from historical climate data). The landslide assessment utilized data on past landslides from the Kentucky Geological Survey (KGS). Similarly, KGS data on known sinkholes was used in conjunction with geologic mapping of karst regions to identify the exposure of transportation assets to future sinkhole formation. For roadway segments only, these analyses were augmented with input from district staff on known/possible locations of exposure to each hazard, asset criticality, and the anticipated severity of impacts. This resulted in a relative ranking by vulnerability of NHS road segments within the district.

The pilot study indicated a significant number of assets and NHS miles that could be affected given different levels of hazard intensity. For example, an earthquake having a peak ground acceleration (PGA) of greater than 60% of gravity could affect 109 NHS miles, 33 NHS bridges, 12 large culverts, and 39 structures. A 100-year flood could affect 28.9 NHS miles, 79 bridges, 18 culverts, and three structures. A worst-case scenario for District 1 was defined as the simultaneous occurrence of a major earthquake followed by major flooding. In addition, the pilot study identified two communities that could be isolated with the extreme flooding of access roads. The pilot study demonstrated the value of conducting a vulnerability assessment and was the basis for extending the study to other KYTC districts. A significant takeaway was that the involvement of KYTC officials and engineers in the process yielded valuable contributions to the assessment.

TRANSPORTATION SYSTEM VULNERABILITY AND RESILIENCE TO EXTREME WEATHER EVENTS AND OTHER NATURAL HAZARDS - FINAL RESULTS OF VULNERABILITY ASSESSMENT OF NATIONAL HIGHWAY SYSTEM FOR ALL KYTC DISTRICTS (2018):[2]

This study was a follow-on study to the District 1 Pilot Project. Desktop analyses and district-level workshops throughout the Commonwealth were used to identify NHS asset vulnerabilities to the same primary hazards of concern identified in the pilot study: earthquakes, floods, landslides, and sinkholes. Like the pilot, overlays of hazard data from a desktop analysis were combined with workshop-based inputs on exposure, asset criticality, and the anticipated severity of impacts to

[2] Blandford, B., S. Schurman, and C. Y. Wallace. 2018. Transportation System Vulnerability and Resilience to Extreme Weather Events and Other Natural Hazards — Final Results of Vulnerability Assessment of National Highway System for All KYTC Districts, Report KTC-18-08/SPR16-524-1F, Frankfurt, KY: KYTC. Accessed April 18, 2024 from https://uknowledge.uky.edu/ktc_researchreports/1594/

identify potential vulnerabilities to these hazards of NHS road segments, bridges, large culverts, and structures (overpasses).

Although the parameters of the assessment were similar to the pilot study, this study used a different approach to ranking the NHS roadway segments by vulnerability (as in the pilot study, bridges, large culverts, and structures were not individually ranked by vulnerability). For this assessment, a modified version of the FHWA's Vulnerability Assessment Scoring Tool (VAST) was employed.[3] VAST was used to combine the desktop analysis results on exposure with the input received from the district workshops into a common four point vulnerability rating scale where, for each of 22 separate exposure, sensitivity, and adaptive capacity metrics, a value of one indicated lowest vulnerability and a value of four indicated the highest vulnerability. The scaled values were combined mathematically in VAST to compute relative rankings of NHS roadway segments by the hazard types studied (earthquakes, sinkholes, flooding, and landslides). Summaries of the analysis results and workshop feedback were provided both statewide and on a district-by-district basis.

The results of this statewide vulnerability assessment provided a good high-level overview of potential NHS disruptions due to natural hazards. Of the 287 NHS segments studied statewide, 83 were expected to be highly vulnerable to either earthquakes, floods, landslides, or sinkholes. Of these segments, 13 had high vulnerability to two hazard types and one additional segment had high vulnerability to three hazard types. In addition to the identification of vulnerabilities, the study asked participants to describe the worst-case hazard scenario for the district in terms of disruption to the NHS. In some cases, the identified scenario was a type of hazard (e.g., major earthquake) while in other cases the scenario was specific to a particular asset (e.g., flood/landslide closing of the Mountain Parkway in District 10).

The value of the information produced in this study was stated as, "These assessments illuminate potential issues before they result in major incidents or closures. Drawing on information from these assessments will create a more up-to date and well-maintained transportation system by helping officials identify and resolve issues before they grow and become unmanageable." As noted in the study, however, the VAST results were simply a screening of potential vulnerability. More detailed engineering analysis would be needed to identify appropriate mitigation measures for locations of high vulnerability.

ASSET MANAGEMENT, EXTREME WEATHER, AND PROXY INDICATORS (2019):[4]

This pilot study focused on establishing a framework to identify asset risks related to natural hazards and incorporate such information into the KYTC asset management system. The intent was to support the identification of mitigation strategies that could prolong the useful life of NHS assets, and in essence develop a risk-based asset management program as required by federal regulations. The study examined two major climate threats—higher temperatures and more precipitation—and their potential impacts on two major asset types—pavements and bridges.

Three research efforts were conducted to provide the basis for developing the desired framework. The first was the development of a screening tool that leveraged National Bridge Inventory (NBI) data

[3] Data inputs for VAST are organized into three types: (1) asset exposure to climate stressors, (2) sensitivity of an asset to different climate stressors, and (3) asset adaptive capacity (level of resilience) in the event of damage or disruption.

[4] Blandford, B., N. Albright, C. van Dyke, E. Lammers, and S. Schurman. 2019. Asset Management, Extreme Weather, and Proxy Indicators. Accessed April 18, 2024 from asset_management_extreme_weather.pdf

fields for identifying bridge and large culvert sensitivity to flooding. The tool combines various NBI metrics associated with asset criticality, structural condition, and geomorphic sensitivity into a score that can be used to rank bridges based on their flood vulnerability. As part of the study, it was applied to large culverts and bridges (over water) throughout the state. The tool application was found to be, "straight-forward and can be implemented without performing additional fieldwork," a desired characteristic of such analyses. The study also concluded that, "the methodology was a cost-effective and simple way of characterizing structural sensitivities at the inventory level."

The second research effort developed a methodology for using temperature projections from climate models for pavement design with the Mechanistic Empirical Pavement Design (Pavement ME) software. A case study application of the methodology was completed in the Bowling Green area wherein future pavement performance for a roadway under a high climate change scenario (Representative Concentration Pathway [RCP] 8.5) was predicted for both a 20- and 40-year pavement life. The study found that predicted pavement distresses due to climate change were within expected normal variations of existing climate conditions in that area, and thus the study concluded that existing pavement design procedures did not have to be changed at that location.

The third research effort assessed current KYTC asset management processes to identify areas where the consideration of resilience concerns could be enhanced. This resulted in several recommendations. The first recommendation was to update how KYTC tracks and monitors its involvement in the FHWA ER program. The study developed a geospatial database for ER projects back to the year 2009. Not only will continuing this database help KYTC satisfy FHWA 23 CFR Part 667 requirements, but it will also provide important input into project characteristics in the asset management program. Another recommended change was to update the way in which KYTC assigns activities to ER projects, including those activities not in the immediate scope of ER efforts. Other recommended process improvements included: (1) continued integration of how KYTC keeps track of ER-related costs, (2) developing an approach for determining how maintenance activities can prepare for extreme precipitation events prior to their occurrence, (3) establishing a Resiliency Working Group within the agency, and (4) continuing to incorporate extreme weather risk into KYTC's asset management program and in the asset management plan.

KENTUCKY LONG-RANGE STATEWIDE TRANSPORTATION PLAN (2022):[5]

The KYTC updated its Long-Range Statewide Transportation Plan (LRSTP) in 2021-2022. The Plan includes an appendix and a section in the Plan on the challenges of climate change to Kentucky and how the Cabinet is addressing them. In comparison to many other state DOTs, the KYTC has provided much more attention to climate change in its long-range statewide transportation plan.

As part of the plan development process, an online survey was conducted to identify the issues that matter the most to the citizens of Kentucky and whose results were to help shape the direction of statewide transportation planning between now and 2045. From this input, the Cabinet identified five guiding principles intended to help the agency achieve its adopted goals. One of these guiding principles was:

[5] Kentucky Transportation Cabinet. 2022. Kentucky 2022-2045 Long-Range Statewide Transportation Plan. Frankfurt, KY. Accessed at https://transportation.ky.gov/Planning/Long%20Range%20Plans%20Documents/2022-2045%20LRSTP%20Documents/2022-2045%20LRSTP%20Long-Range%20Statewide%20Transportation%20Plan.pdf Last accessed July 12, 2024.

- Adaptability/Sustainability: Develop and operate a system that can adjust to the potentially disruptive forces of advances in technology, funding challenges, or human-made and natural disasters.

This input led to the establishment of a goal in the plan to, "deliver a high level of maintenance and resiliency" for the Commonwealth's transportation system. Resilience related objectives under this goal included, "protect transportation infrastructure from extreme weather events" and "provide a level of redundancy to the system."

Furthermore, a scenario planning exercise was undertaken during plan development. This exercise incorporated a consideration of a "Survival Modes" scenario which, among other things, pondered more frequent severe weather and attendant disruptions to the transportation system. This scenario informed the development of the plan's policy recommendations. One recommendation was to expand the focus of projects, including to promote resiliency in infrastructure design. Another recommended focusing on asset management and preservation including protecting assets from extreme weather events. It was also noted that a focus on resilience might necessitate the hiring of new staff with the appropriate skillsets, some of which may not be traditional to a DOT. Changes to KYTC's organizational structure to promote resilience were also contemplated.

In the implementation plan, continued coordination with the Federal Emergency Management Agency (FEMA) and the Kentucky Division on Emergency Management (KYEM) relating to recovery and funding of repairs to damaged assets was noted. In addition, further collaboration with the University of Kentucky and the United States Geological Survey'(USGS) on predictive models for resilience was also noted. These actions were assigned to the Secretary's Office, the State Highway Engineer's Office, and the Office of Highway and Safety. Another resilience-oriented action item was to consider explicitly further investments in resiliency in areas that had previously experienced disasters in order to promote system reliability. Responsibility for this was assigned to the Secretary's Office, the State Highway Engineer's Office, the Division of Planning, and the Division of Program Management. Lastly, an action item on adjusting the design process to promote "durability" was assigned to the Secretary's and State Highway Engineer's Office.

KYTC TRANSPORTATION RESILIENCE IMPROVEMENT PLAN (2023):[6]

The KYTC-adopted RIP was one of the first such documents in the nation. As noted in the Plan, it reflects "KYTC's efforts to identify vulnerabilities, develop risk-based strategies, and schedule and prioritize improvements. This Plan serves as the baseline in developing a more robust resilience planning program within the agency." In response to federal guidelines, the RIP was developed in coordination with, and will be implemented consistently with, several other KYTC and state plans, including the Transportation Asset Management Plan (TAMP), LRSTP (see above), State Freight Plan, and the Commonwealth of Kentucky Enhanced Hazard Mitigation Plan (EHMP). The studies described above were referenced as the basis for the material found in the RIP.

The RIP re-cast the district-level findings on flooding, landslides, earthquakes, and sinkholes from the statewide vulnerability assessment into a qualitative risk-based framing that considers the likelihood and consequence of impacts from various natural hazards. The analysis was also extended to additional hazards including wind/severe storms, drought, dam failure, wildfire, and heat. **Figure 1** shows the summary of KYTC infrastructure risks to each hazard in each of the 12 KYTC districts.

[6] Kentucky Transportation Cabinet. 2023. Transportation Resiliency Improvement Plan.

Figure 2 summarizes the different types of NHS assets that could be affected for different types of hazards.

KYTC District	Flood	Wind / Severe Storms	Drought	Dam Failure	Wildfire	Landslide	Heat	Earthquake	Sinkhole
1	2C	1D	3E	5A	4D	3C	1D	4A	3D
2	2C	1D	3E	5A	4D	3D	1D	4B	2C
3	2C	1D	3E	5A	4D	3D	1D	4C	1B
4	2C	1D	3E	5A	4D	3C	1D	5C	1B
5	2C	1D	3E	5A	4D	4D	1D	5D	2C
6	2C	2D	3E	5A	4D	2B	2D	5E	4D
7	3C	2D	3E	5A	4D	4D	2D	5E	3C
8	2C	2D	3E	5A	3D	2C	2D	5E	3C
9	2B	2D	3E	5A	3D	2B	3D	5E	4D
10	2A	3D	3E	5A	3D	1B	3D	5E	4D
11	2A	3D	3E	5A	3D	1B	3D	4D	4D
12	2A	3D	3E	5A	3D	1B	3D	5D	4D

Consequence	Likelihood				
	1. Very Likely	2. Likely	3. Medium	4. Unlikely	5. Very Unlikely
A. Catastrophic	1A	2A	3A	4A	5A
B. Major	1B	2B	3B	4B	5B
C. Moderate	1C	2C	3C	4C	5C
D. Minor	1D	2D	3D	4D	5D
E. Insignificant	1E	2E	3E	4E	5E

Figure 1: Level of KYTC Infrastructure Risk to Various Natural Hazards, by KYTC District

Asset Type	KYTC Total	PGA* ≥ 60	PGA ≥ 30 and < 60	PGA ≥ 18 and < 30	100-yr Flood Plain	Major Karst Potential	Mod. Karst Potential	High Landslide Potential	Mod. Landslide Potential
Total NHS Road Miles**	6,151	194	425	771	229	1,921	848	1,372	401
Interstate	2,064	31	161	241	49	762	398	290	56
Parkway	1,034	60	61	218	33	209	174	59	77
US Highway	1,932	101	128	295	97	694	136	613	181
KY Routes	1,076	2	76	17	49	227	141	409	86
Local Road	44	0	0	0	0	29	0	0	0
Bridges***	772	51	93	143	431	149	46	231	67
Culverts	292	12	21	21	166	86	40	75	27
Structures	1,409	56	109	178	26	462	188	205	86

***Maximum Peak Ground Acceleration (PGA) with 2% likelihood of exceedance in 50 years. PGA accounts for energy released by an earthquake and how the energy travels through soil and rock.**Centerline miles. ***Includes only those listed in the National Bridge**

Figure 2: Number of Assets Potentially Affected by Hazard Type

The RIP did not identify priority investments or investment types. However, it did note that research will be conducted to identify how transportation asset classes have been impacted by extreme weather and natural hazards. The research will then, "use the historical record and the projected precipitation and temperature changes to project the future impacts of extreme weather to transportation assets across the Kentucky regions." These results will then be used to determine the most beneficial resilience-oriented improvements. As KYTC moves forward with its resilience efforts, the RIP provides a good starting point for doing so in a cost-effective and systematic way.

EXPERIENCE WITH RECENT DISASTERS

Kentucky has experienced natural disasters throughout its history. In recent years, however, the pace and scope of disasters has increased. Kentucky has recently faced two very large disasters, a major tornado outbreak in western Kentucky in 2021 and substantial flooding in eastern Kentucky in 2022. The level of KYTC effort in disaster response and recovery is often significant because KYTC owns and maintains a large proportion of the roadway system in the Commonwealth. This section summarizes KYTC experience with disaster response and recovery sourced from discussions with KYTC staff and a review of the KYEM after-action reports for the 2021 tornado outbreak and 2022 floods.

One item that was stressed in the staff discussions is that each event is unique and the types of impacts on the road network differ by event. For example, a major part of KYTC's response to the tornados was removing debris from the roads. There was also damage to signals, panel boxes, mast arms, and lighting. The eastern Kentucky floods, on the other hand, resulted in bridge losses and roadway erosion (mostly to the county network; bridges on the state network faired quite well) and many landslides, slips, and rockfalls.

Funding to repair damaged roads after recent disasters was obtained by KYTC from both the FHWA Emergency Relief (ER) Program (for federal-aid roads) and FEMA (for repairs on the remainder of the network and debris removal on all roads). It was noted that it would be more efficient to have a common reimbursement approach between these two agencies rather than having two different systems for doing the same thing. KYTC has a system of establishing a charge cost (OMS) that can be used to charge expenses related to a disaster even before a governor's declaration that can be used to track disaster-related costs. This code is applied to both immediate emergency repairs as well as continued maintenance needs that might occur later due to the damage suffered (this system is also set up by vendor code). This code is critical for getting reimbursed by the federal government under the programs noted above and can also be a useful data point for future resilience planning efforts.

Both the FEMA and FHWA ER programs will fund betterments, improvements to the asset design beyond current state design standards to make it more resilient, if they can be shown to be cost-effective and save the programs money in the long run. KYTC has not gone beyond its typical design standards and requested betterments in response to recent disasters although some design specifications have been updated.[7] That said, bringing damaged assets up to current design standards often involves increasing resilience relative to what had been in place before. For example, in eastern Kentucky roads are often built along an embankment with little shoulder width. KYTC has adopted a "rail and cribbing" design for normal roadway replacement projects in these areas that mitigates flood-induced erosion. This design was used to repair roads after the 2022 floods thereby increasing the resilience of these roads over what existed prior. It was noted that FHWA was more understanding of adding in these resilience enhancement measures than FEMA was, likely because they understand transportation assets better and have a more vested long-term stake in the assets and the performance of the highway system.

It was noted by staff that better record-keeping on impact documentation is an important task that, in the past, delayed reimbursement from federal agencies. For example, panel signs on highways were destroyed in the 2021 tornado outbreak. KYTC went through the federal process to get these replaced but, due in part to documentation lapses, it took 1.5 years to happen. In retrospect, it would have been much quicker to use state funds. To avoid such issues in the future, KYTC noted they now use FHWA's Mobile Solution for Analysis and Reporting (MSAR) to document impacts and manage the ER application process. This system allows KYTC and FHWA to share information and facilitate reimbursements. MSAR is a GIS-based program where KYTC can take a picture of the damage with associated notes, upload it to MSAR, and have it reviewed by FHWA. KYTC pays for the license to use the system. FEMA has its own portal, but it does not have a mobile GIS data collection component.

[7] For example, truss design was changed from aluminum to steel after the 2021 tornado outbreak to help mitigate damage from future tornados and high wind events. Also, KYTC has required counties to increase their design standards if using state funds. For example, given the poorer performance of county bridges during the 2022 eastern Kentucky floods relative to state bridges, KYTC has begun to require the use of their design standards for county bridges built with state money.

Staff also noted that KYTC recognizes the importance of the agency's responsibility for disaster response and recovery and has taken some steps to improve this capability. For example, a new Disaster Aid Training has been created by KYTC. This training will focus on educating more KYTC staff on the steps that should be taken to improve the efficiency and effectiveness of its response to disasters.

Useful information on KYTC-related strengths, areas for improvement, and needed corrective actions with respect to disaster response and recovery comes from KYEM after-action reports on the 2021 tornado outbreak and 2022 floods. To develop the reports, KYEM held meetings with several groups that had been engaged in disaster response to identify what they observed were the most important issues faced in this response. The transportation-related responses, shown in Table 1, came from the Emergency Support Function (ESF) representatives stationed at the State Emergency Operations Center, the county emergency managers from eastern Kentucky, and representatives from Incident Management Teams (IMTs) deployed to the scenes of both disasters. Table 2 summarizes the key take-aways for KYTC from these reports. Note that these reports are organized around key core capabilities in targeted areas such as logistics/supply chain management and critical infrastructure.

MEETINGS WITH EXECUTIVE TEAM, PROJECT DELIVERY/PRESERVATION, AND PROJECT DEVELOPMENT DIRECTORS

The study team convened with three groups from KYTC over a two-day period (June 27-28, 2024), including personnel from the Executive Team, Project Delivery/Preservation, and Project Development. Each group received questions in advance of the meeting to clarify the types of information being sought. These questions were categorized into three areas: past resilience efforts, the current situation, and future actions for KYTC. The following summary highlights some key points discussed regarding past and present KYTC resilience initiatives.

Table 1: Critical Transportation Issues Identified by Disaster Responders

Group	Input on Critical Infrastructure
Eastern Kentucky Emergency Responders	Highway status and clearance coordination: • Counties did not have overall situational awareness of road status. • Coordination between KYTC and county highway departments was lacking.
ESF Partners	Coordination: • Did not have good information to prioritize activities. KYTC reps needed in county EOCs to coordinate activities. • Coordination of information was a problem due to dueling databases. • Designated debris sites should be identified in advance.
IMT	Debris removal: • Fallen power lines delayed road clearance due to the power company's refusal to remove another utility company's lines. • Each IMT should include debris management expertise. • Routes to vital facilities should be given priority for debris clearance. • The Emergency Resource Inventory List is not maintained by all counties thereby limiting the visibility of sharable resources. • County personnel need training on debris management regarding pickup, segregation, and monitoring.

Source: Abridged from Kentucky Division of Emergency Management. 2024a. DR-4663-KY Flooding After-Action Report and Corrective Action Plan, KYEM Deliberate Planning Unit, Jan.

Table 2: Results and Recommendations from KYEM After-Action Reports

Western Kentucky Tornados, 2021	
Primary Area of Transportation-related Improvement (one of several on many different topics): Debris Removal: Lack of coordination in identifying right-of-way status caused confusion and duplication of effort. Debris disposal sites were not designated in advance. Putting debris management contracts in place post-disaster delayed removal operations. Critical Transportation Recommendation: Develop and implement a method (computer database, GIS dashboard, online emergency operations center [WebEOC] board, etc.) to be used by KYTC and local highway departments to establish a common operating picture for debris removal.	
Emergency Support Function (ESF)	**Analysis/Areas for Improvement**
Core Capability: Logistics and Supply Chain Management Issues	
Logistics (ESF 7) FEMA Response Capabilities	Issue: KYTC was unaware of FEMA's capabilities at the beginning of the response. This was generally true of all ESF stakeholders. This caused issues in understanding FEMA's roles and responsibilities and the resources FEMA brought to the response. Corrective Action: Conduct briefing for all ESFs on expectation for FEMA support vs. Commonwealth and local government response.
Operations	Issue: KYTC was unfamiliar with FEMA capabilities at the beginning of the response. Corrective Action: Same as above.

Core Capability: Critical Transportation Issues	
Transportation (ESF 1) Debris Clearance Contracts	Issue: There were no debris management contracts in place prior to the event. This required ESF 7 to identify contractors during the event and resulted in longer response times. Corrective Action: Establish standing debris management contracts in place.
Eastern Kentucky Flooding, 2022	
Primary Area of Improvement (one of several): Lack of coordination in identifying right-of-way status caused confusion and duplication of effort. Debris disposal sites were not designated in advance. Putting debris management contracts in place post-disaster delayed removal operations.	
Emergency Support Function (ESF)	**Analysis/Areas for Improvement**
Core Capability: Logistics and Supply Chain Management	
Logistics (ESF 7)	Issue: KYTC was unaware of FEMA's capabilities at the beginning of the response. This was generally true of all ESF stakeholders. This caused issues in understanding FEMA's roles and responsibilities and the resources FEMA brought to the response effort. Corrective Action: Conduct briefing for all ESFs on expectation for FEMA support vs. Commonwealth and local government response.
Core Capability: Critical Transportation - Strength of Response	
Transportation (ESF 1) Debris Removal	KYTC, the Kentucky National Guard (KYNG), and the Kentucky Division of Forestry (KDOF) worked well together in coordinating debris removal. KYTC dispatched 200 trucks to facilitate debris management.
Transportation (ESF 1) Bridge Inspection	KYTC performed over 1,000 bridge inspections during the course of the response.
Core Capability: Critical Transportation Issues	
Transportation (ESF 1) Situational Awareness	Issue: Counties did not have overall situational awareness regarding open roads. Corrective Action: Develop and implement a method (computer database, GIS dashboard, WebEOC board, etc.) to be used by KYTC and local highway departments to establish a common operating picture for debris removal.
Transportation (ESF 1) Conflicting Databases	Issue: Conflicting information in multiple databases presented coordination challenges between KYTC and Kentucky State Police (KSP). Corrective Action: Combine databases into a single database of transportation features.
Transportation (ESF 1) ROW Clearance	Issue: Debris clearance teams had difficulty in identifying previously cleared areas. This caused confusion and duplication of effort regarding roadway clearance. Corrective Action: Develop a survey dashboard to show road clearance status
Transportation (ESF 1) Utility Easement Obstruction	Issue: During road clearance operations debris was pushed into utility easements thereby hindering pole replacement. Corrective Action: Debris clearance personnel should be trained on proper relocation of debris.

Transportation (ESF 1) Bridge Ownership	Issue: Ownership and maintenance responsibility of bridges are not clearly identified. This lack of knowledge impedes USACE when attempting to contract for bridge repair. Corrective Action: A comprehensive list of bridges should be developed and maintained. This could be done through county or ESF 1 reporting.

Source: Abridged from Kentucky Division of Emergency Management. 2024a. DR-4663-KY Flooding After-Action Report and Corrective Action Plan, KYEM Deliberate Planning Unit, Jan; and Kentucky Division of Emergency Management. 2024b. DR-4630-KY Tornado Outbreak After-Action Report and Corrective Action Plan, KYEM Deliberate Planning Unit, Jan.

During the meetings, staff pointed to several examples, beyond the KTC-led studies discussed above, where KYTC has undertaken pro-active, resilience-related efforts. These include:

- Studying earthquake retrofits of bridges in western Kentucky.
- Incorporating flood risk enhancements into the design of the Mountain Parkway Project.
- The Planning group could initiate discussions on resilience, with a particular focus on adopting a risk-based perspective. For instance, project prioritization now incorporates considerations of roadway criticality and the availability of detours. Asset management has integrated "criticality" into its prioritization methodology, with 10% of the capital improvement scoring dedicated to resilience. Metropolitan Planning Organizations (MPOs) have developed their own prioritization processes, with some increasing the weighting for resilience to exceed 10%.
- Access to hospitals and major freight generators is being considered as part of project planning. KYEM would like to see prioritization also given to accessing airports (which are key to recovery efforts).
- Encouraging the geotechnical staff to look at hazards in advance of a project, including potential landslide locations (Planning helped initiate this effort).
- Having Project Development assess culverts for replacement when projects are designed. Design exceptions occur when it is determined that the context and past experience warrant design criteria more robust than those adopted by KYTC.
- Undertaking a major detour study (involves traffic operations, the state police, etc.) to understand how traffic might have to bypass road closures.
- Conducting structural inspections by Maintenance to ensure assets meet standards; Construction conducts inspections to make sure constructed facilities and assets relating to resilience meet required performance standards.
- Considering depreciation, lifecycle costs, etc. for acquisition of traffic equipment. KYTC is moving to newer signal controllers in part due to past experience of such controllers in disasters.
- Disseminating information both internally and to the public on disaster preparation and the importance of resilience.
- Reverting to non-cellular technology (e.g., two-way radios, satellite phones) to offer an alternative communication mechanism should the cellular network go down after a disaster.

- Instituting a policy making it easier for staff from one district to assist staff in other impacted districts.
- Improving projections of maintenance needs with respect to KYTC fleet management and forecasting equipment failure prior to it happening in the field.

A question was asked if KYTC currently has a formal detailed policy on resilience that ties these efforts together. It was noted that no formal policy exists at this point, but participants seemed receptive to have such a policy. Participants noted that resilience *is* incorporated into KYTC's adopted goals and objectives, however, there was a sense that it was a lower priority than other goals as evidenced by the limited resources devoted to it.

The participants were also asked to identify the major challenges/issues facing KYTC in terms of enhancing its consideration of resilience in system or project decision-making. The following challenges were identified:

- Resilience funding, for both projects and new staff, is lacking. Staff doing post-disaster resilience work are being re-assigned from their main jobs. There is also a loss of institutional knowledge on the performance of an asset during past extreme weather events as people retire.
- Staff's ability to consider resilience when they most likely do not know what it is, and the number of personnel is limited (understaffed). Included in this was a concern that there is inadequate information on future conditions, so even if there was adequate staff they would most likely not know how to use it. More generally, one participant noted that, "everyone has a response mentality, given recent disasters around the state; need to shift this to a more pro-active view."
- One participant noted that individual project development is ultimately the responsibility of district leads, thus a greater emphasis on resilience would need to get buy-in from them. Resilience is layering another concern on project developers who are already overloaded.
- Every design policy is written in a way that it can be flexibly applied, and it is up to the engineers working on projects to do so. However, the agency culture has been resistant to such flexibility thinking that exceptions (say, to enhance resilience) are "wrong" and should be avoided.
- There is a need to understand better the performance of assets during extreme events. Are design standards performing adequately?
- Resilience needs to be incorporated into all aspects of project development and as early in the process as possible. For example, one participant noted that resilience should be incorporated into the environmental process. However, incorporating resilience into all aspects of project development might require some changes in standard operating procedures.
- Data gaps exist in areas that are critical for considering resilience investments. For example, there are gaps in KYTC's asset inventory. Work is currently underway for improving this (e.g., for small drainage networks). One participant felt that KYTC is characterized by siloed data. For example, it's unclear whether different groups are aware of the data generated by other groups.

- Competition for funds and staff resources for other KYTC goals such as safety, economic mobility, congestion relief, and the like. One participant noted an internal struggle over doing "new stuff vs. maintaining what is already out there" (coupled with the challenge that the legislature has control over the program).
- Value engineering (VE) serves an important role in agency decision-making. However, in the context of resilience enhancements which often require additional project funding, VE can often be a barrier to incorporating resilience strategies into a project. There is tension in incurring higher up-front costs at times even though there might be downstream benefits; staff has often had difficulty differentiating cost from value during the VE process. KYTC leadership has been working on this and has recognized that the cheapest thing is not necessarily the most valuable thing to do. The general challenge with resilience is that it has long-term benefits but higher short-term upfront costs. It thus becomes hard to justify and quantify the benefits.
- The political environment in the state is not conducive to considering climate change as part of project development (although resilience is a less "loaded" term). If one makes the issue local and based on real world impacts, people have a better chance of understanding what is being discussed. KYTC has found that chambers of commerce and MPOs are receptive to resilience discussions. However, KYTC's public engagement efforts are lacking with respect to this topic
- Public awareness is not very "deep" on the causes of weather-related disruptions. There is an understanding of the symptoms, but the public does not understand the causes and what KYTC has done to prevent damage and disruption. KYTC does not really message this through a resilience lens.
- Obtaining resilience funding is a challenge (not "sexy" for the legislature; more expensive than the current maintenance budget can handle).

KEY TAKEAWAYS AND RECOMMENDED ACTIONS

From the review of materials noted above and discussions with KYTC staff, it's clear that KYTC has made notable progress in incorporating resilience concerns into its decision-making and operating procedures. Some of the key characteristics of these early efforts include:

- Much work has been done to understand current and future climate change vulnerabilities across the network.
- Asset management has been a major focus area of KYTC's resilience efforts. For example, a resilience criterion was incorporated into the asset management project prioritization process. KYTC also participated in an FHWA-sponsored pilot project for demonstrating how resilience could be integrated with asset management plans and processes.
- KYTC has incorporated resilience concerns into several agency initiatives and activities. For example,
    - The LRSTP has a section devoted to resilience and the importance to the Commonwealth of having a resilient transportation system is apparent throughout

  - Geotechnical staff have been asked to examine geohazards in advance of a project to identify where potential risks exist.
  - Project development is assessing culverts for needed replacements before projects are designed.
  - KYTC is conducting a major detour study with the State Police to identify potential detour routes around road segments that are likely to be damaged in the future given their proximity to high hazard areas (e.g., near rivers).
  - Alternative communication systems and technology have been put in place give KYTC's experience with the cellular phone network "going down" during recent disasters.
  - New traffic signal controllers are being procured given the poor performance of the past controllers during disasters.
  - A policy is being instituted to share staff from one district to another to support disaster response.

- There is a willingness (as expressed during the interviews with executive leadership) to implement strategies and actions that lead to a stronger emphasis on resilience in agency decision-making.

This list of achievements and progress with respect to considering resilience in KYTC is an impressive one. However, staff members identified several gaps that hinder the agency's efforts to make further progress. In addition, top executives expressed a desire to continue to improve the progress that KYTC has made, with interest expressed in using risk-based assessment procedures, providing more information to key stakeholders, the public, and to the agency's own staff on why resilience is so important to KYTC and to the Commonwealth. For these actions to succeed, several gaps in KYTC's resilience efforts need to be addressed. These gaps include the following:

- **Overall Policy/Guidance**: KYTC does not have an adopted and articulated policy on the role that resilience should play in its decision and in the types of project designs it produces. As one staff person noted, there is a need for an overall comprehensive resiliency framework for all stages of a project as it goes from planning to maintenance after it is implemented. The point being that resiliency is not just considered in planning, project design or emergency management; it should be a concern that transcends all functional areas within the agency and be integrated throughout this process.
  - Recommendation: Develop and adopt a policy statement on the importance of resilience to KYTC and to the Commonwealth.
  - Recommendation: Modify the current resilience goal (if necessary) and/or better integrate resilience into KYTC's other goals that can be used in transportations plans, internal guidance, and in materials aimed at external stakeholders.
- **Resilience Integration with Other Plans and Programs:** As noted earlier, KYTC was one of the earliest state DOTs to develop a RIP, to link it to the long-range transportation plan, and to consider how resilience factors can be integrated with asset management. However, a

critical examination of what is said in the documents does not provide a good sense of what KYTC is doing with respect to resilience, what it wants to do, and how it will get to where it wants to be in furthering resilience goals. Doing so might start with adopting a formal resilience policy, goal, or agency guidance (see above)

  - Recommendation: Examine how resilience is integrated (or not) in other KYTC plan, program, and guidance documents. Recommend changes to each that can be adopted for the next updates of these documents.

- **Implementation of Future Climate Risks Adaptation:** Much of KYTC's future climate risks adaptation work (as opposed to general resilience work) to date has been research-based. The primary focus has been to identify the types and potential impacts of the natural hazards KYTC is facing today and will likely face in the future. Unlike other aspects of resilience work, there has been less mainstreaming of climate adaptation, including use of future climate projections, into everyday agency activities.
  - Recommendation: KYTC should consider future climate projections in any activities that could be influenced by climate/weather. Examples include:
    1. Considering future projections in the design of new projects
    2. Dedicating resources to explore adaptation alternatives for assets found to be vulnerable during the systems-level vulnerability assessments (but not otherwise slated for project work in the near-term)
    3. Considering how adaptation needs can be incorporated into the project scoring/programming process.
- **Risk-based Decision-making:** There was a general interest in exploring how risk-based decision-making could be incorporated into KYTC decision-making processes. However, certain data required for this purpose is currently not collected and is not readily accessible. In addition, analysis tools and benefit/cost processes that support this type of decision-making are not typically being used by KYTC. Developing such tools and identifying related data would also require staff training on how to use the tools and collect the data.
  - Recommendation: Develop a clear statement of resilience benefits and how they can be considered in KYTC decision-making (e.g, in justifying betterments in FHWA ER applications).
  - Recommendation: Develop and adopt risk-based analysis tools and methodologies that can be used to support agency decision-making.
  - Recommendation: Develop a strategy for developing the data that supports risk-based decision-making.
- **Funding**: Funding is always a constraint and one that is difficult to overcome. The PROTECT program provides some funding that can be allocated to resilience-oriented actions, but the level of funding is very limited. Several states have adopted a strategy to allocate funds for incremental resilience improvements to projects in the development phase. This approach is comparable to the seismic retrofit initiative implemented by KYTC in western Kentucky.

  - Recommendation: KYTC may consider evaluating how this strategy could be implemented in its highway program. Additionally, there appears to be a lack of understanding regarding what qualifies for PROTECT funding among staff not involved with the program. This could be clarified through guidance or training. Given the potential scale of future needs, KYTC might also explore the development of new financing concepts such as public-private partnerships for resilience investments.

- **Staff Resources and Knowledge:** The staff interviewed felt that many in KYTC do not understand how resilience is defined and, more importantly, the benefits of investing in resilience actions. This is an important gap in KYTC's organizational capacity for considering resilience actions in its everyday and longer-term efforts. Several mentioned that training could be very useful in addressing this issue as well as providing examples from other states where resilience efforts have resulted in quantifiable benefits.
  - Recommendation: Examine current training opportunities offered to KYTC staff and consultants and identify how resilience concerns could be incorporated.
  - Recommendation: Provide opportunities for KYTC staff to be exposed to training targeted on resilience, either through existing courses or by developing its own course(s).
- **Design:** Staff members expressed that "other than standard" design parameters could be applied in a project design through the design exception process. However, it was also noted that the agency culture is such that such design exceptions are not viewed favorably because as one staff member noted they are considered "wrong." There thus seems to be a gap in understanding the types of resilience-oriented designs and design parameters that can be considered as part of a "normal" project development process. Another strategy mentioned was to change the design operating process (that is, make sure the design "checklist" includes resilience factors).
  - Recommendation: Review KYTC project development and design experience with respect to recent disasters and determine if current design criteria are adequate for similar future events where the magnitudes and frequency of occurrence change.
  - Recommendation: Assess KYTC's project development and design guidance to determine how adaptive they are to a range of future hazards.
- **Value Engineering:** KYTC staff noted that there has been a challenge in the value engineering process of distinguishing between costs and values (or benefits).
  - Recommendation: KYTC needs to monitor how value engineering treats resilience-oriented projects and recognize that the cheapest action is not necessarily the most valuable thing to do when considering the asset's full lifecycle costs. This requires recognition that a general challenge with resilience is that its long-term benefits are associated with often higher short-term upfront costs. Thus, it can be difficult to justify and quantify the benefits without using a tool that helps do so.

- **Feedback Loops:** The KYEM after-action reports were an impressive example of post-disaster feedback loops that provides agency staff with an understanding of what went right, what went wrong, and how can KYTC do better in the future. There was a sense among the staff that not enough of such feedback occurs for smaller storm events that cause impacts.
    - Recommendation: Some staff members suggested it would be worthwhile to have a formal feedback mechanism in place to assess how design parameters are responding to natural disasters as part of a formal diagnosis of why assets failed. Others suggested research be conducted on the failure mechanisms for those assets damaged in recent disasters.
- **Emergency Response:** Each region of Kentucky has experienced natural disasters, necessitating state-managed responses. Several staff members believe that while KYTC excels in its response efforts, it faces challenges in preparation and in developing a proactive approach prior to events, which would enable the agency to respond more swiftly and effectively.
    - Recommendation: Examine KYTC's emergency management process and procedures to identify where preparation planning could be enhanced.
    - Recommendation: The KYEM after-action reports have identified several steps KYTC can take to improve its disaster response efforts. As noted earlier, it has already accomplished some. However, it is not clear that the issues relating to contracted services in removing debris have been addressed. Given the importance this issue received in the after-action reports, this should be a top priority for the agency (as one staff member noted, "contractor pre-qualification needs to be a faster process and more nimble").

MEMO

TO: Tracy Nowaczyk (KYTC)

FROM: Elizabeth Farc (WSP), Chris Dorney (WSP), and Mike Meyer (independent consultant)

SUBJECT: Task 1.3.2: Resilience Goals, Objectives, and Performance Measures

DATE: November 6, 2024

INTRODUCTION

This memorandum presents recommendations to KYTC for incorporating resilience concepts and concerns into plans, programs, and other decision-making documents. It serves as a resource document for KYTC managers and staff interested in desired changes or additions to KYTC's current policy and planning foundation for resilience-related decision-making.

The next section presents recommended changes to current KYTC plans, policy documents, and communications strategies. The recommendations are organized in four categories: planning and policy, project development/investments, performance monitoring, and communications. **Appendix A** summarizes the key observations from the Task 1.2 memorandum as a reminder of the earlier effort that led to this memorandum. **Appendix B** provides examples from other state departments of transportation (DOTs) on how they have incorporated resilience into their goals, objectives, and performance measures. **Appendix C** presents examples of resilience performance measures as they could relate to different resilience objectives. Note that the states selected as examples in this memorandum include some of Kentucky's neighboring states as well as other states that represent good practice for the topic discussed in the section. Information from other state DOTs was primarily obtained through Web searches, supplemented by the consultant team's experience working with other states.

RECOMMENDED CHANGES

The following recommendations fall into four major categories:

1. Policy/planning
2. Project development/investments
3. Performance monitoring
4. Communications.

POLICY/PLANNING

1. **Recommendation - KYTC Strategic Plan:** KYTC could consider adding an explicit statement on resilience in the Strategic Plan when it is updated. An example might be:

   "Act as a steward of the investment made in the Commonwealth's transportation system to ensure efficient and resilient system performance."

2. **Recommendation - KYTC Long-Range Statewide Transportation Plan**:[1] When the long-range statewide transportation plan is next updated, KYTC could consider modifying one of the current goals or add a new goal on system resilience. Examples include:

   Modifying an Existing Planning Goal:

   Current: Establish a reliable flow of people and freight.

   Modified: Establish a reliable flow of people and freight on a resilient transportation system.

   New Planning Goal:

   Provide stewardship of the state's transportation system by promoting effective asset management and protecting investments from future environmental risks leading to a more resilient transportation system.

3. **Recommendation - KYTC Resilience Improvement Plan (RIP):**[2] Future updates of the RIP could highlight plans (other than those already included) such as the Enacted Highway Plan and corridor/subarea studies. The stated resilience goal in the RIP could be modified as follows:

   "The goal of this Resilience Improvement Plan is to better place Kentucky to prepare for, respond to, and withstand future extreme weather and natural hazard events in order to provide a more resilient transportation system."

   Also, specific resilience objectives could be included, similar to what was discussed earlier for the Long-Range Statewide Transportation Plan and above for planning, project development, and others.

4. **Recommendation - Corridor and Small Urban Area Planning Guidelines**:[3] Resilience as a planning factor could be part of corridor and small urban area studies conducted or sponsored by KYTC, implemented through supplemental guidance or by developing a KYTC corridor and small urban area planning guideline. In addition, a resilience tool could be developed and be linked to the KYTC website as part of the tools that are already listed for supporting corridor planning. This tool would include how to project future natural hazards, determine weather-related risks and impacts, and the types of resilience strategies that can be considered during the project development process.

PROJECT DEVELOPMENT/INVESTMENTS

5. **Recommendation:** Consider more targeted objectives that reflect the types of climate hazards likely to occur in the Commonwealth (and, quite frankly, allow KYTC to get credit for what it is already doing). The goal-objectives combination could look something like the following (note: if the term "objectives" is not to be used, then one could use "strategies" instead):

[1] KYTC. 2021. Kentucky 2022-2045 Long-Range Statewide Transportation Plan. Kentucky: Frankfurt. Accessed at https://transportation.ky.gov/Planning/Long%20Range%20Plans%20Documents/2022-2045%20LRSTP%20Documents/2022-2045%20LRSTP%20Long-Range%20Statewide%20Transportation%20Plan.pdf. Last accessed October 24, 2024.

[2] KYTC. 2023. Kentucky Transportation Cabinet Transportation Resilience Improvement Plan, July. Kentucky: Frankfurt. Accessed at https://www.erm-portal.com/wp-content/uploads/sites/15/2024/08/KYTC-Resiliency-Improvement-Plan-202306-bfe355f2a24c9e7591e4146a5b7226e1.pdf. Last accessed October 25 2024.

[3] KYTC. 2024. Corridor Planning. Website. Accessed at https://transportation.ky.gov/Congestion-Toolbox/Pages/Corridor-Planning.aspx. Last accessed October 25, 2024; and KYTC. 2024. Planning Studies and Reports Website. Accessed at https://transportation.ky.gov/Planning/Pages/Planning-Studies-and-Reports.aspx. Last accessed October 24, 2024.

Goal: Provide stewardship of the state's transportation system by promoting effective asset management and protecting investments from future environmental risks and impacts leading to a more resilient transportation system.

Objective 1: Encourage innovative design and project development that is sensitive to the environment, its constraints, and the general surrounding natural conditions, both for today and what is expected in the future.

Objective 2: Minimize the risk of loss of life, injury, damage to property, and economic and social dislocations resulting from flood hazards and other extreme weather impacts expected in the future (tornadoes, extreme heat, wildfires, rockslides, and others) as well as earthquakes.

New:

Objective 3: Adopt a risk-based decision-making process that identifies and mitigates expected risks to the integrity of the Commonwealth's transportation system for all units in KYTC, including planning and project development/design.

Objective 4: Become a center of excellence in resilience planning and program development by providing opportunities for KYTC staff and other transportation professionals in the Commonwealth to learn about new approaches to adaptive design and operations.

Objective 5: Provide state leadership and develop partnerships in preparing for, responding to, and recovering from the impacts of extreme weather events, emphasizing emergency response, operations, maintenance, etc.

Objective 6: Communicate to key stakeholders and the public the benefits of incorporating resilience design concepts into KYTC's transportation program (highlight benefits of resilience-oriented strategies for operations, maintenance, asset management, etc.)

Objective 7: Establish a performance management framework for monitoring KYTC's progress toward developing a more resilient transportation system.

Add asset management-related objectives if needed (to be developed by the asset management group)

6. **Recommendation - Data Needs Analysis Studies (DNAs):** KYTC uses DNAs to "gather basic existing data; to identify potential project development concerns; and to better define the project purpose, need, and scope."[4] The DNA study form includes project descriptions relating to such concerns as: modal Interrelationships, social demands and economic development, safety, roadway deficiencies, and potential environmental impacts. The DNA form could add a resilience category to the scoping analysis that highlights potential resilience concerns due to extreme weather and other natural hazards.

7. **Recommendation – KYTC Planning Guidance Manual:** The KYTC Planning Guidance Manual (PGM) provides "a topics-based assessment of Division of Planning responsibilities to serve as both an internal guide for Division of Planning personnel and a reference manual for the Division of Planning's external customers throughout KYTC, as well as the general public."[5] As such, the Manual is important guidance for both internal

[4] KYTC. 2024. Data Needs Analysis Studies. Website. Accessed at https://transportation.ky.gov/Planning/Pages/Data-Needs-Analysis-Studies.aspx. Last accessed October 24, 2024.

[5] KYTC. 2020. Planning Guidance Manual, September. Kentucky: KYTC, Frankfurt. Accessed at https://transportation.ky.gov/Organizational-Resources/Policy%20Manuals%20Library/Planning%20Manual.pdf. Last accessed October 29, 2024.

and external audiences. Two changes could be made. First, the Resilience Improvement Plan (RIP) could be listed and described in the ”Key Plans” section. Second, resilience as a planning concern could be incorporated into the Planning Activity Matrix (Table 2 in the Manual) as a topic that could be supported by the appropriate KYTC Division of Planning Branch. If a resilience performance measure is adopted by KYTC, this could be included in the list of performance measures noted in Section 800 of the PGM.

8. **Recommendation - Enacted Highway Plan, 2024-2030:** The recently adopted Enacted Highway Plan is an important document from a resilience perspective because most of the resilience concerns focus on highway damage and disruptions. Of the three major investment categories recommended in the Plan, two --- asset management and capacity improvements --- explicitly note the concern for resilience in the investment descriptions. The only recommendation for future versions of the plan is to highlight a project or type of project that has potentially significant resilience benefits --- the latest version of the plan highlights priority bridge needs. It notes that the priorities are aligned with the Cabinet’s strategic objectives, so is system resilience gets a larger presence in these objectives, presumably it will be considered in plans such as the Highway Plan. It is clear that, like other states, priority bridges are usually the top need; however, it is recommended that future versions of the Highway Plan highlight investments that enhance system resilience.

9. **Recommendation - SHIFT:** The Strategic Highway Investment Formula for Tomorrow (SHIFT) is the KYTC's approach to compare capital improvement projects and prioritize among the limited transportation funds.[6] Arguably, this approach is one of the most important in the agency in that it decides which projects move forward. The process considers seven key attributes that are scored as part of the process, and as shown in **Figure 1**.

Source: (KYTC 2024)

Figure 1: Factors Considered in the SHIFT Process

As can be seen in the figure, resiliency is one of the factors considered in the process. Apparently, this is done by considering whether a project is on a “critical” roadway. **As KYTC progresses in undertaking risk assessments for individual projects, it is recommended that this “critical” roadway indicator be replaced with a measure or measures that better represents resilience.**

[6] KYTC. 2024. Strategic Highway Investment Formula for Tomorrow (SHIFT). Website. Kentucky: Frankfurt. Accessed at https://transportation.ky.gov/SHIFT/Pages/default.aspx. Last accessed September 15, 2024.

10. **Recommendation – Statewide Planning and Research Program:** The FY 2025 Division of Planning Statewide Planning and Research Work Program was approved by FHWA in July 2024.[7] A review of the document shows that a project to develop a resilience prioritization approach was included in this year's Work Program. It is recommended that future Work Programs include additional resilience-related projects or studies to further KYTC's resilience initiative.

PERFORMANCE MONITORING

11. **Recommendation - Resilience Performance Measures:** Every state collects some data as they relate to national performance measures. In addition, many state DOTs have included performance measures in their planning and investment programs (e.g., asset management) to monitor progress toward a more resilient transportation system and a more capable state DOT. It is recommended that KYTC develop a performance measure framework consisting of both output and outcome measures that can be used in a KYTC "resilience" story. This would include measures that are already part of KYTC's data collection process (e.g., Interstate trip reliability) and relevant metrics from asset management. The additional resilience measures would depend on which would be most important to KYTC managers, but some of those from other state DOTs that seem particularly relevant include the following (**NOTE: we are not recommending all or a majority of these as we realize each measure requires resources to collect relevant data**). These performance measures also relate to the issues identified at the first meeting with KYTC staff.

    - Progress in transitioning the current risk assessment approach to a multi-hazard, quantitative approach.
    - Proportion of projects in each year using a risk-based design approach.
    - Proportion of high-risk existing assets for which a detailed adaptation analysis has been conducted.
    - Effectiveness of KYTC's organizational structure and leadership in supporting emergency response efforts
    - Periodic assessment of KYTC staffing needs in support of the resilience efforts (e.g., need for more GIS staff)
    - Proportion of the total length of major roadways having pre-planned detour routes/closure plans (and similar measures for other modes).
    - Proportion of critical structures and electronic assets that are hardened against the emerging types of extreme weather threats.
    - Existence of updated O&M emergency response plan, including existence of on-call support contracts to provide assistance given the types of disruptions being faced.
    - Existence of updated vegetation management and control strategies reflecting changing environmental conditions.
    - Incorporation of hazard ratings into KYTC's prioritization processes and decision-making.
    - Monitoring the use of resilience factors in allocating non-capital dollars for other KYTC services, not administrative or overhead.
    - Incorporation of resilience-related performance measures into KYTC's performance management system.

[7] KYTC. 2024. FY 2025 Statewide Planning and Research Work Program- Subpart A, SP0020 (042). Kentucky: Frankfurt. Accessed at https://transportation.ky.gov/Planning/Documents/FY%202025%20Work%20Program.pdf. Last accessed September 15, 2024.

- Periodic reassessment of the type of asset condition data needed for risk assessment given changes in environmental conditions.
- Number of KYTC staff who have taken resilience-oriented training courses or who have participated in resilience-oriented professional development meetings or workshops.
- Number of KYTC emergency response staff who have taken training courses or who have participated in development meetings or workshops focusing on future climatic and extreme weather challenges.
- Level of coordination among KYTC and other emergency response partner agencies (as determined through after-action reports).
- Stated (and written) strategy for including resilience concerns into KYTC's overall communications strategy, updated on a periodic basis.
- Incorporation of resilience topics and concerns in internal communication outreach efforts with KYTC staff; assessment of the effectiveness in terms of staff awareness.
- Incorporation of resilience topics and concerns in communications outreach efforts to key KYTC constituencies; assessment of their effectiveness.

The concept is that this information would be used by KYTC managers to identify where additional effort might be necessary to integrate resilience more effectively into agency decision-making. In addition, it is expected that this information could be used to tell the KYTC "resilience" story to key stakeholders and to the public.

COMMUNICATIONS

Consistently communicating KYTC's experience with and its strategy for enhancing transportation system resilience is an important part of a state DOT's resilience strategy. Clear internal communications can bolster participation and buy in from staff. Through external communications focusing on key audiences, KYTC can build a constituency for investing in resilience improvements to the transportation system that will have important benefits to the Commonwealth.

12. **Recommendation - Internal Documentation:** Prepare written internal documentation stating KYTC's definition of resilience, resilience goals, and an established means of exchanging information amongst staff and coordinating resilience efforts where necessary.
13. **Recommendation – KYTC Successes**: Highlight KYTC resilience successes on a range of traditional and social media outlets. Emphasize the benefits of investing in transportation system resilience.
14. **Recommendation – Assess Effectiveness**: Periodically assess the successes and failures in resilience communication strategies to identify those that have been effective and those that may need to be adjusted or discarded from use. This will permit the agency to emphasize communication strategies that have proven successful.
15. **Recommendation – Partner Agencies**: Continue to support a broader resilience communications strategy that includes other agencies to promote consistent messaging on the importance of resilience in the transportation system.
16. **Recommendation - Dissemination:** Update and refine the information disseminated on KYTC's resilience efforts. Updates would best occur on a set schedule and focus on information found on KYTC's website.

APPENDIX A: SUMMARY OF RECOMMENDATIONS FROM TECHNICAL MEMORANDUM 1.2: REVIEW OF KYTC RESILIENCE EFFORTS TO DATE

Overall Policy/Guidance

- Develop and adopt a policy statement on the importance of resilience to KYTC and to the Commonwealth.
- Modify the current resilience goal (if necessary) and/or better integrate resilience into KYTC's other goals that can be used in transportations plans, internal guidance, and in materials aimed at external stakeholders.

Resilience Integration with Other Plans and Programs

- Examine how resilience is integrated (or not) in other KYTC plan, program, and guidance documents. Recommend changes to each that can be adopted for the next updates of these documents.

Implementation of Future Climate Risk Adaptation

- KYTC could consider future climate projections in any activities that could be influenced by climate/weather. Examples include (1) considering future projections in the design of new projects, (2) dedicating resources to explore adaptation alternatives for assets found to be vulnerable during the systems-level vulnerability assessments (but not otherwise slated for project work in the near-term), and (3) considering how adaptation needs can be incorporated into the project scoring/programming process.

Risk-based Decision-making

- Develop a clear statement of resilience benefits and how they can be considered in KYTC decision-making (e.g, in justifying betterments in FHWA ER applications).
- Develop and adopt risk-based analysis tools and methodologies that can be used to support agency decision-making.
- Develop a strategy for developing the data that support risk-based decision-making.

Funding

- KYTC might want to see how such a strategy might be applied in its highway program. In addition, there seems to be a gap in general understanding on what is eligible for PROTECT funding (among staff not involved with the program). This could be addressed through guidance or training. Given the potential scale of the future need, KYTC might also consider exploring the development of new financing concepts like public-private partnerships for resilience investments.

Staff Resources and Knowledge:

- Examine current training opportunities offered to KYTC staff and consultants and identify how resilience concerns could be incorporated.
- Provide opportunities for KYTC staff to be exposed to training targeted on resilience, either through existing courses or by developing its own course(s).

Design

- Review KYTC project development and design experience with respect to recent disasters and determine if current design criteria are adequate for similar future events where the magnitudes and frequency of occurrence change.
- Assess KYTC's project development and design guidance to determine how adaptive they are to a range of future hazards.

Value Engineering

- KYTC needs to monitor how value engineering treats resilience-oriented projects and recognize that the cheapest action is not necessarily the most valuable thing to do when considering the asset's full lifecycle costs. This requires a recognition that a general challenge with resilience is that its long-term benefits are associated with often higher short-term upfront costs. Thus, it can be difficult to justify and quantify the benefits without use of a tool that helps do so.

Feedback Loops

- Some staff members suggested it would be worthwhile to have a formal feedback mechanism in place to assess how design parameters are responding to natural disasters as part of a formal diagnosis of why assets failed. Others suggested research be conducted on the failure mechanisms for those assets damaged in recent disasters.

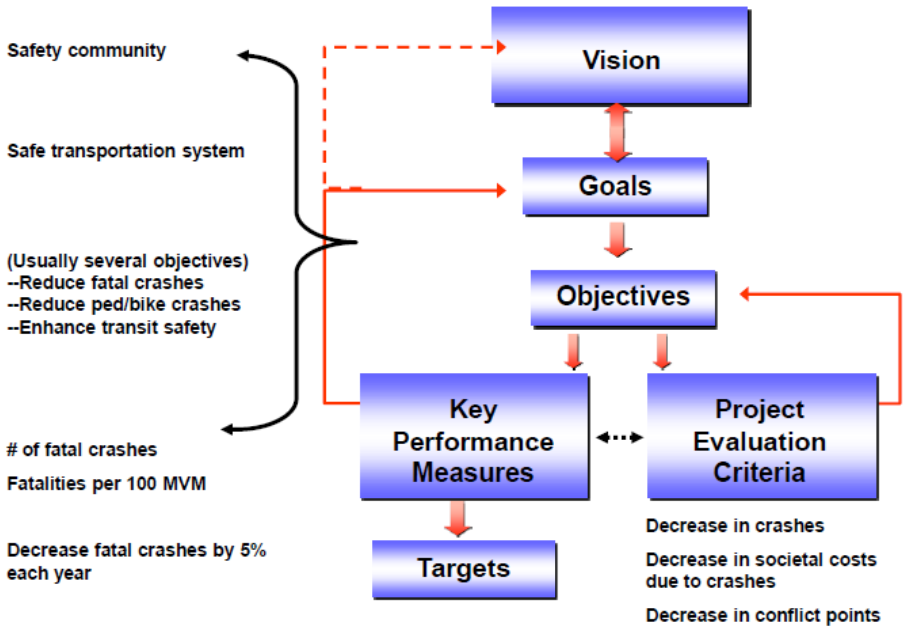
Emergency Response

- Examine KYTC's emergency management process and procedures to identify where preparation planning could be enhanced.
- The KYEM after-action reports have identified several steps KYTC can take to improve its disaster response efforts. As noted earlier, it has already accomplished some. However, it is not clear that the issues relating to contracted services in removing debris have been addressed. Given the importance this issue received in the after-action reports, this might be a top priority for the agency (as one staff member noted, "contractor pre-qualification needs to be a faster process and more nimble").

APPENDIX B: REVIEW OF OTHER STATE DOT CONSIDERATION OF RESILIENCE IN DECISION-MAKING DOCUMENTS

GOALS, OBJECTIVES, AND PERFORMANCE MEASURES: TERMINOLOGY

This section clarifies the terms goals, objectives, and performance measures, as they are often confused in practice. Sometimes plans refer to goals when they mean objectives, or strategies when they mean objectives. To understand the rest of this memorandum, we need a common understanding of these terms. **Figure 2** shows how goals, objectives, and performance measures relate to each other and to other key planning terms like vision, project evaluation criteria, and targets. The figure uses a safety example to illustrate these concepts.



Source: (Meyer and Miller 2024)

Figure 2: Policy and Planning Hierarchy of Guiding Concepts

Goals, objectives, and performance measures are defined below, with more focus on performance measures due to their recent inclusion in transportation planning.

Goals provide the overall direction for an agency in terms of the desired ultimate outcomes of agency action and reflect the agency's vision for the future of transportation and of transportation's role in society. Examples include supporting economic development, enhancing environmental quality, improving quality of life, and providing a safer and more resilient transportation system. They are defined at a high level often with very generalized statements. Follow-on objectives and performance measures reflect the goals adopted by the agency, thus identifying the most important goals for a transportation agency, plan, or program is well worth the time spent doing so. Goals are also often linked very closely to an agency's mission statement.

Objectives provide more specific policy directions for achieving the adopted goals. For example, as shown in the figure, a goal of improving safety could have objectives relating to reducing fatal crashes, reducing injury crashes,

reducing vehicle-pedestrian crashes and the like. A resilience example for a goal of developing a more resilient transportation system might include the following resilience-oriented objectives: 1) Identify at-risk transportation assets and facilities to projected climate hazards, 2) Ensure future project designs include adaptive design concepts to minimize risks of damage or disruption, 3) Plan for and implement emergency response strategies in light of more frequent extreme storms of greater-than-historic magnitudes, and 4) Develop partnerships with other public agencies, private firms, and non-profit organizations to promote joint strategies to avoid or mitigate damage from climate hazards.

Objectives also provide more detail for identifying appropriate performance measures, as well as helping to define the evaluation criteria that could be used in assessing which investment projects are more cost effective.

Performance measures serve several purposes. First, and most importantly, the collection of data on key metrics that represent the condition and performance status of the transportation system provides decision-makers with an assessment of how the transportation system is performing over time. As noted by the Florida DOT, the resilience performance measures in its Resilience Improvement Plan (RIP) were intended to "monitor and regularly report existing and new performance measures on the resilience of the State Highway System."[8] In some sense, they can provide decision-makers with a "snapshot" of how their investments are affecting what the users of the transportation system are facing on a day-to-day basis. They thus serve as a feedback loop into decision-making, helping to identify where policy and investments should be focused to meet the goals established by the state DOT (the feedback loop in Figure 1).

Second, performance measures provide an ability to promote consistency among the different levels of government that are investing in the transportation system. Thus, for example, the national transportation performance measures established in federal law[9] are intended not only to provide a sense of how the transportation system is performing, but also to ensure that all states are monitoring the same metrics. It is interesting to note that some of these national performance measures relate to transportation system resilience, such as the pavement and bridge condition measures, and the Interstate, non-Interstate, ant truck travel-time reliability measures.

Third, performance measures have become an important part of providing accountability for governmental programs aimed at achieving a particular set of policy goals. For example, for the expenditure of funds to improve the safety of the transportation system (e.g., reducing fatal and injury crashes), one would want to know the extent to which such expenditure is actually achieving these outcomes. Most state DOT RIPs have focused attention on how performance measures can be used as noted in the Utah DOT's RIP to "track progress toward improving resilience and the impact of the projects funded through the PROTECT program to better align the RIP with the agency performance measurement."[10]

It is not the intent of this memorandum to suggest KYTC needs to have such a hierarchical relationship of goals, objectives, and performance measures (although KYTC comes close to having this construct). Simply, the focus on

---

[8] Florida DOT. Undated. Resilience Improvement Plan. Florida: Tallahassee. Accessed at https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/office-of-policy-planning/resilience-(opp)/factsheet_fdot_rip_draft_final.pdf?sfvrsn=e27fbc7a_3. Last accessed September 11, 2024.

[9] Primarily defined in the Moving Ahead for Progress in the 21st Century Act (MAP–21) (Pub. L. 112–141) and the Fixing America's Surface Transportation (FAST) Act (Pub. L. 114–94), although some minor changes have occurred in subsequent legislation.

[10] Utah DOT. 2024. Resilience Improvement Plan. Salt Lake City: UT. Accessed at https://www.erm-portal.com/wp-content/uploads/sites/15/2024/09/2024-05-07-FINAL-UDOT-RIP-eee071ab388ba424f01311f4404fd110.pdf. Last accessed September 11, 2024.

goals, objectives, and performance measures provides a good conceptual framework for collecting and summarizing information from other state DOTs as it relates to the consideration of resilience concerns in agency decision-making.

GOALS (THE WHAT?)[11]

KENTUCKY

KYTC's adopted strategic plan provides the vision, mission, and goals for KYTC's actions and investments. For example, the mission statement is: "To provide a safe, efficient, environmentally sound and fiscally responsible transportation system that delivers economic opportunity and enhances the quality of life in Kentucky."[12] The five strategic plan goals were:

- Goal 1: Promote Safety in All Decision Making
- Goal 2: Strengthen Stakeholder and Customer Relationships
- Goal 3: Deliver Economic Opportunities and Enhance Quality of Life
- Goal 4: Optimize Performance through People and Innovation
- Goal 5: Nurture a Culture of Diversity and Inclusion

The most recent 2024-2030 Highway Plan reaffirms a commitment to a risk-based asset management approach by stating that "This approach reflects the Cabinet's strong commitment to its Transportation Asset Management (TAM) framework, which:

- Links planned investments to performance expectations.
- Extends the service life of the transportation system economically using low-cost treatments early in an asset's service life.
- Reduces agency risk and exposure from unplanned events such as flooding.
- Enhances system resilience."[13]

With respect to the Statewide Long-Range Transportation Plan, KYTC identified the vision for the plan as ensuring "a viable, reliable, and resilient multimodal transportation system to provide access and mobility for all users for the safe movement of people and goods."[14] Five goals were identified in the plan that aligned with the seven national performance goals established in federal legislation: These five goals included:

[11] Note that the state DOT examples provided in the following sections primarily come from a search of state DOT Web sites that usually only provide the latest adopted plans and policy statements. Thus, in some cases, the examples might already be 2 to 3 years out-of-date of what an agency is doing today. In some cases, state DOTs note in their Web page that a new plan or policy is in the process of being developed.

[12] KYTC. 2022. Strategic Plan, 2022-2026. Kentucky: Frankfurt. Accessed at https://osbd.ky.gov/strategic-plans/Documents/KYTC%20Strategic%20Plan%20-%202022-2026.pdf. Last accessed September 13, 2024.

[13] KYTC. 2024. Recommended Highway Plan, 2024-2030. Kentucky: Frankfurt. Accessed at https://transportation.ky.gov/Program-Management/Documents/2024%20Recommended%20Highway%20Plan.pdf. Last accessed September 13, 2024.

[14] KYTC. 2021. Kentucky 2022-2045 Long-Range Statewide Transportation Plan. Kentucky: Frankfurt. Accessed at https://transportation.ky.gov/Planning/Long%20Range%20Plans%20Documents/2022-2045%20LRSTP%20Documents/2022-2045%20LRSTP%20Long-Range%20Statewide%20Transportation%20Plan.pdf. Last accessed September 12, 2024.

- Enhance safety
- Deliver a high level of maintenance and resiliency
- Establish a reliable flow of people and freight
- Provide local, regional, and global connectivity for communities
- Deliver and operate a system that protects or enhances the natural and human environment

In addition, five guiding principles were defined for the long-range statewide transportation plan. Each of these guiding principles could be related in some way to the concept of resiliency, but one, adaptability/ sustainability, explicitly addressed resiliency.

> "Adaptability/Sustainability: Develop and operate a system that can adjust to the potentially disruptive forces of advances in technology, funding challenges, or human-made and natural disasters."

KYTC included an appendix addressing changing environmental conditions and their challenges for the Commonwealth and its transportation system.

HAWAII

Hawaii is geographically, economically, and demographically as distant from Kentucky than almost any other state. However, the Hawaii DOT has invested heavily in developing strategies to enhance the resiliency of the state's transportation system and thus provides an interesting example of an organizational resiliency strategy. Resiliency, one of the goals in the Hawaii Statewide Transportation Plan, is described as follows (Note: other aspects of Hawaii DOT's approach are discussed in subsequent sections):

> "The strategies aimed at addressing transportation system resiliency include adapting to weather and climate change impacts, maintaining the supply chain and movement of goods, and improving transportation system response to public health crises. In addition, the resiliency strategy incorporates emphasis on emergencies preparation through evacuation plans, multiagency cooperation, and improved communications to the public."[15]

ILLINOIS

The current Illinois DOT Long-range Statewide Transportation Plan (the 2024 update should be completed by the end of 2024) identifies five goals: 1) economy, 2) livability, 3) mobility, 4) resiliency, and 5) stewardship.[16] The chapter on resiliency goes into detail on what IDOT is doing to make the transportation system more resilient, and interestingly makes the following observation on how system resilience relates to the other goals:

"The following describes the importance of resiliency as it relates to the other LRTP goals:

> Safety – Resiliency involves providing a safer transportation system for system users, while also reducing the dangers for first responders

[15] Hawaii DOT. 2023. Hawaii Statewide Transportation Plan. Hawaii: Honolulu. Accessed at https://hidot.hawaii.gov/administration/files/2022/12/HawaiiStatewideTransPlan_Draft_compressed.pdf. Last accessed September 12, 2024.

[16] Illinois DOT. 2019. Illinois Long-Range Transportation Plan (LRTP). Illinois: Springfield. Accessed at https://idot.illinois.gov/content/dam/soi/en/web/idot/documents/about-idot/misc/planning/idot-lrtp-1-introduction4119df.pdf. Last accessed September 12, 2024.

Mobility – Resiliency involves minimizing disruptions which can impact the user experience, causing delays and/or major inconveniences

Economy – Resiliency involves minimizing the socioeconomic costs of disruptions caused by impairment of travel/goods movement

Stewardship – Resiliency involves minimizing long-term costs for infrastructure repair/maintenance."

The chapter also discusses resilience objectives and performance measures, which will be discussed in following sections.

IOWA

The 2022 Iowa DOT Long-Range Transportation Plan adopted the following vision for the transportation system:

> "A safe and efficient multimodal transportation system that enables the social and economic wellbeing of all Iowans, provides enhanced access and mobility for people and freight, and accommodates the unique needs of urban and rural areas in a sustainable manner."[17]

The focus of the stated goal is on mobility, which was defined with four outcomes: safety, sustainability, accessibility, and flow. Resiliency (and as noted reliability) was described under the "flow" outcome as well as stewardship. As noted,

> "Resiliency and sustainability are building blocks of stewardship. The Iowa DOT has the responsibility not only to meet the expectations of the public to ensure that the system is available and in good condition, but that it will continue to be so in the future, despite pressures from fiscal constraints and increasing natural disasters."

Interestingly, IDOT did not develop overarching performance measures, but rather asked agency units to do so to assure the most appropriate measures could be identified and monitored at the unit level.

MARYLAND

The Maryland DOT's 2050 Statewide Transportation Plan is the most recent plan reviewed (and thus reflective of federal requirements and resilience funding opportunities).[18] Five guiding principles were defined that established the policy foundation for the plan. Resilience, one of these five, was defined as: "Improve the transportation system's ability to provide reliable service throughout natural weather events and man-made threats." Resilience was also part of two of four goals, "Safety and Security" and "Deliver System Quality".

MINNESOTA

Minnesota DOT's (MnDOT's) 2022 vision for the state's transportation system noted in the Statewide Multimodal Transportation Plan (SMTP) was that the system:

- Connects Minnesota's primary assets—the people, natural resources and businesses within the state—to each other and to markets and resources outside the state and country.

---

[17] Iowa DOT. 2022. 2022 State Transportation Plan, Objectives and Considerations. Iowa: Des Moines. Accessed at https://iowadot.gov/iowainmotion/files/Iowa-in-Motion-2050-Ch4.pdf. Last accessed September 12, 2024.

[18] Maryland DOT. 2024. 2050 Maryland Transportation Plan (MTP). Maryland: Annapolis. Accessed at https://www.mdot.maryland.gov/OPCP/MTP_Playbook_web.pdf. Last accessed September 12, 2024.

- Provides safe, convenient, efficient and effective movement of people and goods.
- Is flexible and nimble enough to adapt to changes in society, technology, the environment and our economy.[19]

Three goals were identified within this vision: 1) quality of life, 2) environmental health, and 3) economic competitiveness. The plan also notes 16 goals established by the legislature (these are really objectives) none of which included changing environmental conditions or resilience. However, a recent update of the plan amended the earlier version to include an emphasis on changing environmental conditions. As noted, "The SMTP focuses on how the transportation system—not just individual people—can act to combat climate change." MnDOT also undertook one of the most comprehensive efforts in the country to develop a RIP that was linked to the SMTP and other planning documents.

OHIO

The Ohio Long-range Statewide Transportation Plan adopted seven goals: 1) safety, 2) environmental stewardship, 3) preservation, 4) efficiency & reliability, 5) quality of life, 6) economic competitiveness, and 7) mobility & accessibility.[20] Each goal has a set of objectives attached to them. Resilience is found under safety with the following initiative mentioned, "Risk – Identify and mitigate transportation facilities at risk from extreme weather events."

OREGON

The 2023 update to the Oregon DOT's Oregon Transportation Plan included the following vision:

> "Oregon's transportation system supports all Oregonians by connecting people and goods to places in the most climate-friendly, equitable, and safe way."

This vision also leads to,

> "A transportation system that is resilient in the face of seismic and climate events and impacts to the degradation of the natural environment are reduced. Transportation infrastructure is built in a way that avoids impacts on key habitat and results in better environmental conditions for wildlife and native vegetation."

It placed an emphasis on changing environmental conditions and system resilience with "investments planned over multiple decades to prioritize seismic deficiencies on key lifeline routes, coastal erosion mitigation, culvert replacements needed for increasingly severe flooding events, landslide mitigation, and emergency service access for wildland firefighting efforts."[21]

The primary interest in resilience (it is mentioned in other goals under the concept of reliability) is found in the following goal:

---

[19] Minnesota DOT. 2022. Minnesota GO, Statewide Multimodal Transportation Plan. Minnesota: St. Paul. Accessed at https://minnesotago.org/final-plans/smtp-final-plan-2022/chapter-1. Last accessed September 12, 2024.

[20] Ohio DOT. 2020. Access Ohio, 2045, Ohio's Transportation Plan. Ohio: Columbus. Accessed at https://www.transportation.ohio.gov/wps/wcm/connect/gov/369f5c73-12f1-4d24-8b88-fc66717a268e/AO45_OhiosTransportationPlan_8.5x11_LowRes_12012020.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_K9I401S01H7F40QBNJU3SO1F56-369f5c73-12f1-4d24-8b88-fc66717a268e-nsvU8Nn. Last accessed September 12, 2024.

[21] Oregon DOT. 2023. Oregon Transportation Plan. Oregon: Salem. Accessed at https://www.oregon.gov/odot/Planning/Documents/Oregon_Transportation_Plan_with_Appendices.pdf. Last accessed September 12, 2024.

"Guided by open, data-driven decision-making processes, secure sufficient and reliable revenue for transportation funding and invest public resources to achieve a resilient and sustainable multimodal transportation system."

The ODOT website also notes that ODOT's RIP was approved in 2023 by the Federal Highway Administration (FHWA) and has been "integrated into the state transportation plan."

TENNESSEE

Three objectives (really goals) were identified in the Tennessee DOT 25-year Long-Range Transportation Policy Plan: 1) Promote efficiency, 2) Increase effectiveness, and 3) Emphasize economic competitiveness.[22] The plan identifies seven guiding principles each of which could have a system resilience element, but resilience is not mentioned explicitly. A policy paper was provided on Safety, Security, and Transportation Resilience, which states that resilience is related to the guiding principle "Preserve and Manage the Existing System" by protecting existing assets through programs and policies resulting in a more resilient transportation system."[23]

VERMONT

The Vermont Agency of Transportation identified goals for its RIP that augmented the adopted transportation goals for the state (shown in **Figure 3**).[24]

1. **Less damage in the future.**
Major natural events result in *less damage* to the transportation system in the future than in the past.

2. **Systems return to normal quickly.**
The transportation system *returns to normal quickly* after major events.

3. **Vermont is resilient for <u>all</u> people.**
All people have transportation options to safely evacuate before an incoming natural event or after if necessary.

4. **Essential freight moves.**
Essential freight continues to arrive at key destinations for distribution and delivery to Vermonters.

5. **Resilience efforts are coordinated.**
Resilience investments benefit transportation systems *<u>and</u>* Vermont's communities, environment, economy, and other critical infrastructure sectors.

Source: (Vermont Agency of Transportation 2024)

Figure 3: Vermont Agency of Transportation Resilience Goals

[22] Tennessee DOT (TDOT). Undated. TDOT 25-Year Long-Range Transportation Policy Plan, Summary. Tennessee: Knoxville. Accessed at https://www.tn.gov/content/dam/tn/tdot/documents/TDOT_LRTP_Summary_Final.pdf. Last accessed September 12, 2024.

[23] TDOT. Safety, Security, and Transportation Resilience Policy Paper. Tennessee: Knoxville. Accessed at https://www.tn.gov/content/dam/tn/tdot/documents/Safety_022316.pdf. Last accessed September 12, 2024.

[24] Vermont Agency of Transportation. 2024. Resilience Improvement Plan. Vermont: Montpelier. Accessed at https://storymaps.arcgis.com/stories/f67e4a5fa5404f008682b8da3f401be2. Last accessed September 14, 2024.

SUMMARY

The review of the state DOT policy and planning goals, augmented by the consultant's own experience in developing state transportation plans and RIPs, lead to the following observations:

1. Before the federal opportunity for obtaining resilience funding, many state DOTs had already identified enhancing system resilience as a goal in their transportation plans. This was influenced by the occurrence of large-scale extreme weather disasters impacting many states' transportation systems, an increased awareness of changing environmental conditions among professionals and the public. It is notable that 10 years ago, system resilience was not included in state transportation plans, programs, or public outreach materials, except in cases where states faced serious seismic risks to their transportation systems.

2. Many states have explicitly linked resilience to other transportation goals with the understanding that a resilient transportation system supports economic development, promotes safe mobility and access, contributes to public health, and the like. In many instances, resilience is listed as a "co-benefit" of a transportation system investment.

3. The states that have developed an RIP have noted that it is linked to, or has become part of the statewide transportation plan, thus enhancing even further the consideration of resilience in agency decision-making. This is not surprising given what FHWA resource material states on what should be included in an RIP and how it should fit into a state DOT's planning and programming processes.

4. KYTC's high-level consideration of resilience in the statewide transportation plan is certainly in line with the more advanced state efforts at integrating resilience into overarching policy and decision-making guidance. This is particularly notable in the statewide transportation plan along with other state DOT transportation plans and programs, such as asset management.

5. This latter observation leads to the question of whether additional KYTC policy statements or planning guidance is necessary to reinforce the importance of resilience in decision-making. For example, KYTC could feature resilience more prominently in the Strategic Plan when it is next updated. This could be done by adding another strategic goal, something like:

   Act as a steward of the investment made in the Commonwealth's transportation system to ensure efficient and resilient system performance.

OBJECTIVES (THE HOW?)

KENTUCKY

KYTC's asset management plan and program is one of the areas where resilience-related objectives have been incorporated into agency decision-making. The current Transportation Asset Management Plan (TAMP) provides some background on what these objectives are and how the asset management program is dealing with climate-related risks.[25] KYTC describes its TAM process in part using the characteristics of such process as recommended by the FHWA.

[25] KYTC. 2022. Transportation Asset Management Plan. Kentucky : Frankfurt. Accessed at https://transportation.ky.gov/Maintenance/Documents/KYTC_2022%20TAMP%20BIL%20Submittal.pdf. Last accessed September 13, 2024.

- Policy-Driven – Decisions are aligned with policy goals and objectives that define the desired system conditions and service levels.
- Performance-Based – Reliable condition and performance information is used to establish targets, allocate funding, and monitor progress
- Risk-Based – A formal risk-management process is used to prioritize mitigation strategies to reduce the likelihood and/or impact of uncertainty while enhancing system resilience.
- Option-Oriented – Comprehensive choices and trade-offs are evaluated at each level of decision making in alignment with strategic objectives and consideration of available resources.
- Data-Driven – Credible and current data are evaluated using analysis tools that support investment decisions.
- Transparent – Decisions are based on performance-based results that are clearly conveyed to stakeholders.

Each of these characteristics is important, but for resilience the first three are critical. In essence, they say that TAM reflects the policy directions established by KYTC and that risk-based and performance-oriented analysis will be used to provide the most cost effective investment strategy for the Commonwealth. The TAMP also notes that, "to enhance KYTC's ability to manage resilience of the bridge inventory, it has developed a Bridge Prioritization Index, which quantifies concerns for safety, condition, mobility, and risk. The objective of adopting this approach is to "offset the potential damage these risk events may cause."

HAWAII

Hawaii DOT identified several objectives under its resiliency goal. These objectives addressed both the general approach toward enhancing resilience, as well as focused on particular characteristics of certain types of disruptions. They included:

Goal: Enhance resiliency of transportation systems to the impacts of climate change, public health crises, and other disruptions by:

Objectives:

- Adapting to climate change, storms, pandemics, and other disruptions
- Facilitating robust, resilient, and sustainable supply chains and goods movement systems
- Improving system resiliency to public health crises

Goal: Improve emergency preparedness, response, and evacuation by:

Objective:

- Anticipating and preparing for system emergencies

ILLINOIS DOT

The Illinois DOT established a set of resilience objectives along with corresponding performance measures as part of the long-range statewide transportation plan that were specific to each objective.[26] Table 1 shows the five resilience-related objectives and associated performance measures. Note that most of the objectives are resilience-specific such as "minimize the frequency and duration of facility closures due to extreme events and other disruptions" or "identify current and future transportation system vulnerabilities to extreme events and climate change." However, one objective "Improve safety on the Illinois transportation system by reducing the number of injuries/fatalities attributable to extreme events" is related to extreme events, but reducing the number of injuries/fatalities on the transportation system is also a component of the safety goal. This highlights the concept that the same objectives and performance measures can be used for different goals if they contribute to achieving each goal.

Table 1: Illinois DOT Resilience Objectives and Performance Measures

Objective	Performance Measures
Improve safety on the Illinois transportation system by reducing the number of injuries/fatalities attributable to extreme events	• Number of flood-flow deficient bridges and culverts • Number of state route closures due to flooding • Number and proportion of extreme events for which outreach/social media campaigns are undertaken
Minimize the frequency and duration of facility closures due to extreme events and other disruptions	• Number of facility closures (or capacity limitations) attributable to extreme events • Number of response plans incorporating natural or man-made disasters
Enhance transportation system redundancy	• Number of major roadways with at-risk areas having pre-planned detour routes/closure plans and similar measures for other modes • Total length of major roadways with at-risk areas having detour route signage (or plans for rapid reaction temporary signage)
Identify current and future transportation system vulnerabilities to extreme events and climate change	• System-wide vulnerability analysis results that are based on the latest information
Address transportation system vulnerabilities to extreme events and climate change within the transportation planning, design, and asset management processes	• Number of and funding amount for resiliency-related projects. • Number/weight of resilience factors in the performance-based project selection tool. • Number of design projects using a risk-based design approach, considering climate change projections.

[26] Illinois DOT. 2019. Long-range Transportation Plan, Resiliency. Illinois: Springfield. Accessed at https://idot.illinois.gov/content/dam/soi/en/web/idot/documents/about-idot/misc/planning/idot-lrtp-5-resiliency-final.pdf. Last accessed September 11, 2024.

	• Number of specific asset types of high-vulnerability assets for which a detailed adaptation analysis has been conducted. • Number of extreme weather risks identified and addressed in the asset management plan.

Source: (Illinois DOT 2019)

MARYLAND

The Maryland DOT associated a resilience guiding principle with several planning goals, but it was prominently found in the goal relating to safety and security, defined as emergency response, as seen below.

Goal: Enhance Safety and Security

Objective: Maintain a safe system during adverse weather events, man-made threats, and other system disruptions

Strategies:

- Standardize operations, response, and scene safety practices with first responders and other key partners.
- Implement unified incident command with first responders.

Performance Measures:

- Annual number of fatalities and serious injuries on all roads in Maryland
- Annual number of bicycle fatalities and serious injuries
- Annual number of pedestrian fatalities and serious injuries
- Annual number of fatalities and serious injuries on all roads in historically disadvantaged communities in Maryland.

The DOT also indicated which of the other objectives also had a linkage to the resilience guiding principle --- eight objectives were indicated as having such a linkage. This included such objectives as: 1) Accelerate project completion through improved project delivery, and 2) Increase the percentage of state-owned or funded facilities and assets in a state of good repair

OREGON

The Oregon DOT identified the following statement as the primary resilience-related objective in its statewide transportation plan (note: this is more of a goal).

> "Increase the resiliency of the transportation system to better withstand and recover from the anticipated impacts of climate change, extreme weather, seismic, and other natural disasters, and adapt to changing needs."

Several actions were listed below this objective as ways of achieving the desired outcomes:

- Leverage transportation investments to support community health and increase community resilience to chronic climate change impacts.

- Identify modal and multimodal lifeline routes to facilitate evacuation and recovery during and after a disaster, as well as to proactively prepare routes as best as possible to reduce possible hazards from an event before it occurs.
- Incorporate pre-disaster mitigation to improve the resilience of Oregon's transportation system, prepare for long-term recovery and reconstruction efforts, mitigate future hazards, and adapt to changing climate conditions.

SUMMARY

The review of state DOT resilience-oriented objectives is not as extensive as was the review of resilience-related goals. This is primarily because many state DOTs do not develop objectives or if they do they are subsumed in other ways of presenting the information. This review of objectives leads to the following observations.

1. KYTC's most developed use of objectives as they relate to resilience is found in its asset management program, not surprisingly given this program has been in place for many years and has benefited from assessments and pilot studies on how to incorporate risk into asset management decisions.
2. KYTC does a good job cross referencing resilience concerns among respective plans or policy statements. For example, the TAMP refers to the Strategic Plan, the Long-Range Statewide Transportation Plan, and the RIP. The Highway Plan refers to the TAMP the Long-Range Statewide Transportation Plan. The RIP refers to all of them. There seems to be an approach and agreement that the plans that guide KYTC decision-making are an important means of conveying the importance of resilience as a decision-making concern. In the future, more targeted or specific resilience objectives could be used for specific KYTC units responsible for implementing a particular plan's recommendations.
3. This latter observation deserves attention at the upcoming in-person meeting in terms of agreeing that resilience-oriented objectives should be part of different KYTC unit operating plans….and be linked back to the RIP or future RIP updates.

PERFORMANCE AND CONDITION MEASURES (HOW ARE WE DOING?)

An important distinction needs to be made between "output" and "outcome" performance measures. Output measures reflect the progress an agency is making toward putting in place the administrative, procedural, and guidance processes that influence how a DOT considers and implements specific resilience actions. It also includes the number of resilience-related projects that have been implemented. An outcome measure, on the other hand, reflects that actual resilience performance of the transportation system. For those RIPs that have recommended performance measures, the majority have focused on output measures.

Outcome measures are much more difficult to conceptualize and define as they relate to DOT decision-making. Thus, for example, the number of resilience projects implemented annually or the number of resilience-related enhancements to existing project designs are both outputs of the agency. They say nothing about the actual resilience nature of the transportation system. Presumably they lead to enhanced system resilience, but they do not measure it. Measures such as the number of bridges closed each year due to extreme weather, the annual amount of time spent on detours around road blockages, or the average time in responding to road closures are actual measures of system resilience. Although outcome measures are more representative of the system resilience characteristics facing system users, they are also often more difficult to collect data on and they can fluctuate widely from year to year, thus requiring data collection over a long time period before detecting trends.

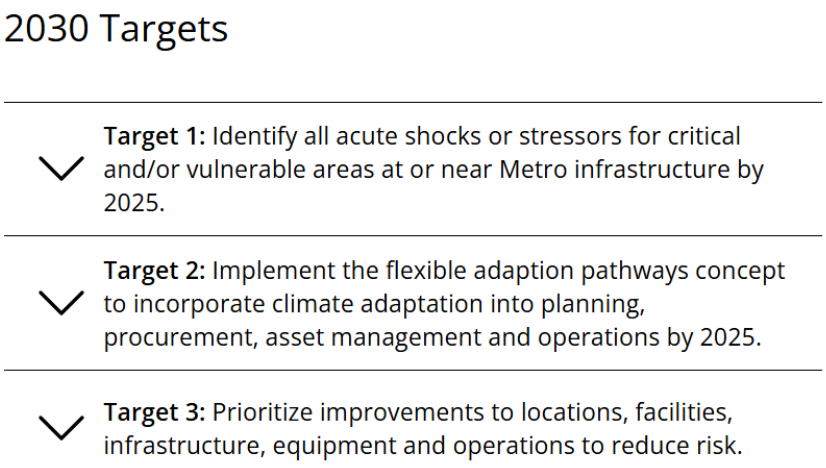
Appendix B provides examples of output and outcome measures as they reflect the resilience framework developed in NCHRP Report 970, *Mainstreaming System Resilience Concepts into Transportation Agencies: A Guide*.[27] This framework consisted of a 13-step self-assessment process for determining an agency's current status with respect to the consideration of resilience concerns in agency decision-making, and for identifying strategies to enhance such consideration. Appendix B shows some of these steps along with corresponding performance measures to monitor the progress toward completing that step.

As noted earlier, asset condition measures used as part of transportation asset management systems play an important role in climate-related risk assessments. This information provides a point of departure for determining the degree to which an asset could be damaged given different levels of stress during extreme weather events. KYTC has a well-developed asset management system and has already included a resilience factor in its project selection process.

Table 2 shows another example of a performance measure framework, although not from a state DOT. The Los Angeles County Metropolitan Transportation Authority (LACMTA) began developing in the mid-2010s a risk-based resilience measurement of its assets for not only climate-related threats but also reflecting seismic risks.[28] As shown in **Table 2**, the LACMTA framework included two major categories of resilience indicators – technical and organizational. Three observations about the information shown in the table merit attention. First, LACMTA is a county agency and thus does not have statewide responsibilities. However, it does have responsibility for a population of more than twice that of Kentucky. Second, the LACMTA has responsibility for all the functions of a state DOT – planning, design, operations, construction, maintenance, and the like. Third, LACMTA is a multimodal transportation agency, thus several of the resilience indicators in the table relate specifically to transit operations. Interestingly, LACMTA has developed a full set of goals, performance indicators, targets, and strategies (in this case, strategies were really a surrogate for objectives). An example of the latter is shown in **Figure 4**.

[27] Dorney, C., M. Flood, M. Meyer, et al. 2021. Mainstreaming System Resilience Concepts into Transportation Agencies: A Guide. Washington, DC: The National Academies Press. Accessed at https://doi.org/10.17226/26125. Last accessed September 13, 2024.

[28] Los Angeles County Metropolitan Transportation Authority. 2019. Metro Climate Action and Adaptation Plan. California: Los Angeles. Accessed at https://libraryarchives.metro.net/DB_Attachments/190701_Climate_Action_Plan_Stakeholder_Update.pdf. Last accessed September 14, 2024; and discussed as well in the LACMTA Sustainability Plan. 2020. Accessed at https://www.transit.dot.gov/sites/fta.dot.gov/files/2022-03/LA-Metro-Sustainability-Strategic-Plan-2020.pdf. Last accessed September 14, 2024.



Source: LACMTA. 2024. Website. Accessed at https://sustainabilityreporting.metro.net/resilience-and-climate-adaptation.

Figure 4: Example Targets for LACMTA's Resilience Process

Table 2: Resilience Indicators from Los Angeles Metropolitan Transportation Authority

Technical Indicators	Organizational Indicators	
Robustness	**Info. Mgt. and Communication**	**Networks and Staffing**
Maintenance	Warnings and Public Awareness	Internal Relationships
Day to Day	Communication Systems – Staff	Information Sharing – Internal
Post Incident	External – Public Awareness	Inter-agency Compatibility
Renewal/Upgrade (Long Range Plans)	Sensors	Business Continuity/Awareness
Design	Data – Access to, and Maintenance of, Key Data Sets	External Information Sharing and Cooperation
Compliance with Current Codes	Information Security and Contingency Planning	Roles and Responsibilities Identified
Condition of Asset	**All Hazards Planning, Preparedness, and Response**	Remote Response Ability
Vulnerability Assessment	Risk Assessment and Scenario Planning	**Leadership and Culture**
Resilience Design Criteria	Tracking Incident-Related Injuries	Resilience Is a Clear Priority of Metro Leadership
Overheating Standards	Tracking Essential Resources	Roles, Responsibilities, and Goals
Other	Priority Routes/Structures	Staff Engagement and Leveraging Knowledge
Extreme Weather Repair Costs	Emergency Management Plans–Existence	Crisis Decision Making
Supplier Utility Robustness – Awareness	Joint Planning	Mid/Long Term Decision Making
Supplier Utility Robustness – Improvement	Training/Drills – Offered	Advance Agreements
Redundancy	Training/Drills/Tests – Completed	Approach to Projects
Alt, Route/Mode Availability	Lessons Learned and Thinking Ahead	
Alt. Route/Mode Capacity	Critical Energy and Supply Chain Provision	
Spare Capacity	**Financial Preparedness**	
Back Up Parts and Equipment	Insurance Coverage	
	Insurance Information	
	Capital Availability	

Re-routing and Communication Plans Supplier Utility Redundancy – Awareness Supplier Utility Redundancy – Improvements	Operational Funding Contingency Funding Modelling	

Source: (LACMTA 2019)

RESILIENCE PERFORMANCE MEASURES IN TRANSPORTATION PLANS

Over the past five years, many statewide transportation plans have included a section on, or at least mentioned, resilience as a concern when investing in a state's transportation system. However, very few have identified performance measures that correspond to resilience goals and objectives that could set the direction for recommended actions. Illinois DOT was one of the few states to do so in its statewide plan (as was shown in Table 1). The above example from Maryland is another illustration of resilience-related performance measures in a transportation plan, although as was noted the suggested performance measures were primarily oriented to other goals (e.g., safety). Another notable example comes from Virginia.

VIRGINIA

In one of the more extensive examinations of performance measures relating to the progress of implementing resilience efforts in a state DOT, the Virginia DOT provided an extensive list of "measures of success" that have been put in place to monitor progress … these would be considered output measures as described above. Table 3 shows these measures.[29]

Table 3: Measures of Success for Virginia DOT's Resilience Efforts

Resilience Strategy	Measures of Success
Adaptive design criteria	• Comprehensive list of adaptive design criteria identified • List of studies related to adaptive design criteria compiled • Evaluation according to applicability and ease of implementation and list of inputs to adaptive design criteria completed • Adaptive design criteria developed • Manuals, standards, guidance documents, and policies revised and published • Research needs and gaps identified • Updates to program budgets, staffing, and revised employee performance standards, as necessary
Other physical enhancement measures	• Comprehensive list of other physical enhancements identified • List of studies related to other physical enhancements compiled • Evaluation according to applicability and ease of implementation completed • List of other physical enhancement measures to adopt finalized • Other physical enhancement design standards developed • Manuals, standards, guidance documents, and policies revised and published as applicable • Research needs and gaps identified • Updates to program budgets, staffing, and revised employee performance standards, as necessary
Natural & nature-based resilience measures	• Comprehensive list of natural and nature-based resilience measures identified • List of studies, tools, and resources related to natural and nature-based resilience measures compiled • Ranking and evaluation according to applicability and ease of implementation completed

[29] Virginia DOT. 2022. Resilience Plan. Virginia: Richmond. Accessed at https://www.erm-portal.com/wp-content/uploads/sites/15/2023/03/VDOT-Resilience-Plan_Nov_2022_FINAL-92cd22fca3674bdb5af0a3eb49a7e62d.pdf. Last accessed September 11, 2024.

	• List of natural and nature-based resilience measures to adopt finalized Research needs and gaps identified • Design criteria and standards developed as appropriate • Manuals, standards, guidance documents, and policies created and/or revised and published • Updates to program budgets, staffing, and revised employee performance standards, as necessary
Operational, maintenance, and emergency management resilience measures	• Comprehensive list of operational, maintenance, and emergency management measures identified • List of studies related to operational, maintenance, and emergency management measures compiled • Evaluation according to applicability and ease of implementation completed • List of operational, maintenance, and emergency management measures to adopt and/or enhanced finalized • Research needs and program gaps identified • Manuals, standards, guidance documents, and policies created and/or revised and published • Updates to program budgets, staffing, and revised employee performance standards, as necessary
Administrative and policy resilience measures	• Comprehensive list of other possible measures identified • List of studies and other research related to other possible measures compiled • Coordination with other federal, state agencies, localities, and MPOs • Evaluation according to applicability and ease of implementation completed • List of measures to adopt • Research needs and gaps identified • Associated regulations, manuals, standards, guidance documents, and policies revised and/or created and published as appropriate • Propose legislation, as appropriate • Updates to program budgets, staffing, and revised employee performance standards, as necessary

Source: (Virgina DOT 2022)

RESILIENCE PERFORMANCE MEASURES IN RIPS

The record of state RIPs including specific resilience performance measures is spotty. Many RIPs note that resilience performance measures are important and will be developed in the future. Others, such as those below, have proposed performance measures.

MASSACHUSETTS

The Massachusetts DOT has invested in actions to prepare for, and respond to, climate change-related disruptions to the Commonwealth's transportation system. For example, the Highway Division has included resiliency considerations in its project scoresheet prioritization process, an environmental scanning tool automatically looks for resilience concerns during the initial project scoping process, and the environmental review checklist includes concerns for resiliency and stormwater control measures. A Statewide Climate Resilience Design Standards Tool has been developed that recommends design standards to use in areas that are considered at-risk to future climate threats, and a "Climate Change Indicator" subsection has been added to the Bridge Design Manual.

Given MassDOT's efforts, it is not surprising that it has developed a performance measure that reflects the progress being made toward a more resilient transportation system. MassDOT noted that many of the performance measures identified in the long-range statewide transportation plan are relevant to resilience and will be monitored for this concern. For addressing the key problem statement of: "Significant transportation

infrastructure in Massachusetts is potentially exposed to natural hazards," MassDOT developed the following performance measure:

> Number of Capital Investment Plan projects that address locations found (through a statewide flood risk assessment) to be vulnerable or at high risk for flooding and other natural hazards.[30]

MICHIGAN

The Michigan DOT's recent RIP did not recommend resilience performance measures but acknowledged the need for them. The RIP indicated that performance measures like those in **Figure 5** would be considered by Michigan DOT.

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

Source: (Michigan DOT 2024)

Figure 5: Candidate Resilience Performance Measures, Michigan DOT

MINNESOTA

MnDOT adopted the following performance measures in its RIP:[31]

Adaptation/Natural Environment

Stormwater Treatment

- Performance Measures: No more than 10% of a transportation system's stormwater treatment features rated in Very Poor and Failing condition (Note: in the traditional definition of performance measures this would be considered a "target")

Trees & Shrubs

- Performance Measure: Percentage of trees and shrubs surviving after 2 years, report separately for rural and urban areas (2 categories)

Native Vegetation - Seeding

- Performance Measure: Percent of seeding using native vegetation

Native Vegetation - Planting

- Performance Measure: Percent of plants using native vegetation

[30] Massachusetts DOT. 2024. Beyond Mobility: Final Plan. Massachusetts: Boston. Accessed at https://www.mass.gov/doc/highway-resilience-improvement-plan-report-presented-at-the-massdot-board-meeting-on-may-15-2024/download. Last accessed September 14, 2024.

[31] Minnesota DOT. 2024. Resilience Improvement Plan. Minnesota: St. Paul. Accessed at https://talk.dot.state.mn.us/resilience-improvement-plan. Last accessed September 11, 2024.

Asset Condition & Vulnerability

Highway culvert condition

- Performance Measure: Percent of highway culverts in poor or very poor condition

Bridge culvert condition

- Performance Measure: Percent of bridge culverts in poor condition (NBI 4 or less).

Scour critical bridges

- Performance Measure: Number of scour critical bridges on the trunk highway system

Climate/Extreme Weather Impacts

Flooding/Washouts

- Performance Measure: Dollars spent on maintenance for flooding/washouts annually.

As noted in the RIP, some of the information will be collected via these performance measures will be placed on the MnDOT Performance Measures Dashboard and be part of the annual Transportation System Performance Reports.

VERMONT

The Vermont Agency of Transportation RIP acknowledged the need to measure the degree to which the state's transportation system is becoming more resilient.[32] Future resilience performance measures will be developed with **Figure 6** showing some possible candidates.

Goal	Possible System Measures
There is less damage in the future.	High risk locations that have been made more resilient through capital or program approaches.
Systems return to normal quickly.	Speed of return to reliable travel times.
Vermont is resilient for all people.	Speed of return to regular fixed route transit schedules.
	Efforts completed in locations where high transportation risk and high social vulnerability coincide that will increase ability of vulnerable populations to travel to safety.
Essential freight moves.	Number of ways to get freight to emergency distribution sites
Resilience efforts are coordinated.	Number of transportation resilience efforts specifically developed to also address recommendations of other plans.
	Number of VTrans resilience-related projects specifically designed to also increase resilience of natural systems

Source: (Vermont Agency of Transportation 2024)

Figure 6: Candidate Resilience Performance Measures, Vermont Agency of Transportation

[32] Vermont Agency of Transportation. op cit.

SUMMARY

The review of the state DOT use of resilience performance measures leads to the following observations:

1. Although there are notable examples of the development and use of resilience-oriented performance measures, these are few in number. Many RIPs, however, note that the state DOT intends to develop such measures.
2. In almost every case, resilience performance measures refer to the overall adopted policy or planning goals or performance measures as an indication of progress toward resilience. For example, the federal "reliability" measure, for which data is collected by every state, clearly relates to the resilience of a transportation system, as do pavement and bridge conditions, congestion levels, and other related measures. Others point to pavement and bridge condition metrics as resilience measures. Thus, most states have adopted the position that many of the performance measures already part of the agency's policy and planning program provide important input into system resiliency.
3. For those agencies where performance measures have been identified (even for those where such measures are proposed and not yet adopted), two types of measures are considered --- output and outcome measures. By far, output measures are the predominant form for resilience measurement.
4. Some state DOTs are relying on individual agency units to develop resilience performance measures that are most related to the function and responsibility of each unit.
5. Ensuring consistency among the different performance measures used by a transportation agency is one of the key characteristics of effective system performance monitoring systems. Such consistency means that the different performance measures should be mutually supportive (certainly not contradicting the intent of each) and provide the information that can add more depth in understanding for "higher level" measures.
6. In some cases, state DOTs are planning to incorporate resilience measures into dashboards and/or annual transportation system performance reports.

RECOMMENDATIONS

The review of resilience-related goals, objectives, and performance measures leads to some possible steps KYTC can take to augment its current resilience efforts. As noted earlier, KYTC's early efforts at resilience have put it in a good position with respect to including resilience-related concepts into agency decisions. These efforts have focused on making sure resilience as a concept is found in the major plans and policy statements that guide agency actions. However, more can be done to make sure these high-level resilience concepts are made operational in individual KYTC units. The following recommendations are intended to do so.

<u>Recommendation: KYTC Strategic Plan</u>

When next updated, explicitly add a resilience-oriented goal, something like:

"Act as a steward of the investment made in the Commonwealth's transportation system to ensure efficient and resilient system performance."

<u>Recommendations: KYTC Long-Range Statewide Transportation Plan</u>

The goals related to changing environmental conditions identified in the statewide transportation plan identify key issues facing KYTC and the Commonwealth (the plan notes that the goals are Kentucky's metropolitan planning organizations (MPOs)). The goals that are of particular importance to resilience include:

- Encourage innovative design and development that is sensitive to the environment, its constraints, and the general surrounding natural conditions.
- Minimize the risk of loss of life, injury, damage to property, and economic and social dislocations resulting from flood hazards.
- Preserve the environmental integrity of the natural, cultural, and physical resources.

As described in the review of other state goals, these are at a high level. It is interesting to note that there do not seem to be any goals or objectives targeting the potential climate impacts listed in the plan. These potential impacts included:

- "The state will see an increase in extreme precipitation and heat in the future.
- The western part of the state will see a more dramatic increase in days with extreme heat.
- The central and eastern parts of the state will see a more dramatic increase in extreme precipitation events.
- The eastern part of the state is more prone to rockfalls and landslides.
- The central part of the state is abundant with sinkholes and karst landscape.
- Flooding is an issue throughout most of the state.
- There are seismic zones on both the eastern and western border of the state."[33]

Note that the planning goals include a focus on flooding, but do not link to the other climate hazards listed in the plan. This is understandable given the flooding challenges faced by Kentucky over the past several years. However, besides the other hazards mentioned above, Kentucky has also faced tornadoes and wildfires that have significantly impacted parts of the Commonwealth. The results of the first meeting with KYTC officials indicated that the agency is undertaking many efforts, including participating with other state agencies, to reduce the risks associated with the flooding and non-flooding threats.

When the long-range statewide transportation plan is next updated, KYTC should consider the following. The resilience planning goals should be more focused on the climate challenges facing the state transportation system. Most importantly, either one of the five current goals should be modified to include resiliency, or a new goal should be included:

Modifying an Existing Planning Goal:

> Current: Establish a reliable flow of people and freight.
>
> Modified: Establish a reliable flow of people and freight on a resilient transportation system.

New Planning Goal:

> Provide stewardship of the state's transportation system by promoting effective asset management and protecting investments from future environmental risks leading to a more resilient transportation system.

With respect to the non-flooding climate risks, KYTC should consider providing a general resilience goal and then more targeted objectives that reflect the types of climate hazards likely to occur in the Commonwealth (and quite

[33] KYTC. 2022. op cit. p.51.

frankly allow KYTC to get credit for what it is already doing). Assume the above recommended goal has been adopted by KYTC, the goal-objectives combination could look something like the following (note: if the term "objectives" is not to be used, then one could use "strategies" instead) :

Goal: Provide stewardship of the state's transportation system by promoting effective asset management and protecting investments from future environmental risks and impacts leading to a more resilient transportation system.

Objective 1: Encourage innovative design and development that is sensitive to the environment, its constraints, and the general surrounding natural conditions, both for today and what is expected in the future.

Objective 2: Minimize the risk of loss of life, injury, damage to property, and economic and social dislocations resulting from flood hazards and other extreme weather impacts expected in the future (tornadoes, extreme heat, wildfires, rockslides, and others) as well as earthquakes.

New:

Objective 3: Adopt a risk-based decision-making process that identifies and mitigates expected risks to the integrity of the Commonwealth's transportation system.

Objective 4: Become a center of excellence in resilience planning and program development by providing opportunities for KYTC staff and other transportation professionals in the Commonwealth to learn about new approaches to adaptive design and operations.

Objective 5: Provide state leadership and develop partnerships in preparing for, responding to, and recovering from the impacts of extreme weather events.

Objective 6: Communicate to key stakeholders and the public the benefits of incorporating resilience design concepts into KYTC's transportation program.

Objective 7: Establish a performance management framework for monitoring KYTC's progress toward developing a more resilient transportation system.

Add asset management-related objectives (to be developed by the asset management group)

Recommendations: KYTC Resilience Improvement Plan (RIP)

Assuming the RIP will be updated at some point in the future, KYTC should make some changes in the material included in the plan. Clearly, the actions and projects implemented since the plan was developed should be highlighted. The RIP does a good job of linking the plan to other planning documents – the Long-Range Statewide Transportation Plan, Freight Plan, the Commonwealth's Hazard Enhanced Mitigation Plan, and the Transportation Asset Management Plan . Other plans should be highlighted as well, such as the Highway Plan and corridor studies (note: in updating its corridor planning guidelines, Caltrans incorporated resilience concepts throughout the guidelines). The message should be that the concern for resilience is found in everything KYTC does.

The current RIP notes that "The goal of this Resilience Improvement Plan is to better place Kentucky to prepare for, respond to, and withstand future extreme weather and natural hazard events affecting the transportation system."[34] This goal could still be used although one recommended change is:

"The goal of this Resilience Improvement Plan is to better place Kentucky to prepare for, respond to, and withstand future extreme weather and natural hazard events in order to provide a more resilient transportation system."

The concept of resilience should be reinforced throughout this and other KYTC documents.

It is also recommended that specific resilience objectives be included, similar to what was discussed earlier for the Long-Range Statewide Transportation Plan. In addition, resilience performance measures similar (but not exactly the same) to what was adopted by the Minnesota DOT should be adopted. These are discussed next.

Recommendation: Recommended Highway Plan, 2024-2030

The recently adopted Recommended Highway Plan is an important document from a resilience perspective because most of the resilience concerns focus on highway damage and disruptions. Of the three major investment categories recommended in the Plan, two --- asset management and capacity improvements --- explicitly note the concern for resilience in the investment descriptions. The only recommendation for future versions of the plan is to highlight a project or type of project that has potentially significant resilience benefits --- the latest version of the plan highlights priority bridge needs. It notes that the priorities are aligned with the Cabinet's strategic objectives, so is system resilience gets a larger presence in these objectives, presumably it will be considered in plans such as the Highway Plan. It is clear that, similar to other states, priority bridges are usually the top need; in describing them, however, one could describe the benefits of such investments including enhancing system resilience.

Recommendation: Corridor Planning Guidelines

A review of the KYTC corridor planning website did not find any adopted guidelines for corridor studies.[35] Examples of corridor studies from Kentucky and other states are provided, as are research reports that examine approaches for conducting such studies. A list of tools that can be used in conducting a corridor study is provided.

It is recommended that resilience be part of corridor studies conducted or sponsored by KYTC, implemented through supplemental guidance or by developing a KYTC corridor planning guideline. In addition, a "resilience tool" should be developed and be linked to the website to be part of the tools that are already listed. This tool would include how to project future climate hazards, determine climate-related risks and impacts, and the types of resilience strategies that can be considered during the project development process.

[34] KYTC. 2023. Kentucky Transportation Cabinet Transportation Resilience Improvement Plan, July. Kentucky: Frankfurt. Accessed at https://www.erm-portal.com/wp-content/uploads/sites/15/2024/08/KYTC-Resiliency-Improvement-Plan-202306-bfe355f2a24c9e7591e4146a5b7226e1.pdf. Last accessed September 15, 2024.

[35] KYTC. 2024. Corridor Planning. Website. Accessed at https://transportation.ky.gov/Congestion-Toolbox/Pages/Corridor-Planning.aspx. Last accessed September 15, 2024.

Recommendation: SHIFT: Prioritizing Kentucky's Transportation Dollars

The Strategic Highway Investment Formula for Tomorrow (SHIFT) is the KYTC's approach to compare capital improvement projects and prioritize among the limited transportation funds.[36] Arguably, this approach is one of the most important in the agency in that it decides which projects move forward. The process considers seven key attributes that are scored as part of the process, and as shown in **Figure 7**.

Source: (KYTC 2024)

Figure 7: Factors Considered in the SHIFT Process

As can be seen in the figure, resiliency is one of the factors considered in the process. Apparently, this is done by considering whether a project is on a "critical" roadway. As KYTC progresses in undertaking risk assessments for individual projects, it is recommended that this "critical" roadway indicator be replaced with a measure or measures that better represents resilience.

Recommendation: Statewide Planning and Research Work Program.

The FY 2025 Division of Planning Statewide Planning and Research Work Program was approved by FHWA in July 2024.[37] A review of the document suggests that very little was included in the work program for implementing the KYTC resilience program. It is recommended that future Work Programs include such projects or studies.

Recommendation: Resilience Performance Measures

As described in earlier sections, every state collects some data as they relate to national performance measures. In addition, many state DOTs have included performance measures in their planning and investment programs (e.g., asset management) to monitor progress toward a more resilient transportation system and a more capable state DOT. It is recommended that KYTC develop a performance measure framework consisting of both output and outcome measures that can be used in a KYTC "resilience" story. This would include measures that are already part of KYTC's data collection process (e.g., Interstate trip reliability) and relevant metrics from asset management. The additional resilience measures would depend on which would be most important to KYTC managers, but some of those from other state DOTs that seem particularly relevant include the following (**NOTE: we are not**

[36] KYTC. 2024. Strategic Highway Investment Formula for Tomorrow (SHIFT). Website. Kentucky: Frankfurt. Accessed at https://transportation.ky.gov/SHIFT/Pages/default.aspx. Last accessed September 15, 2024.

[37] KYTC. 2024. FY 2025 Statewide Planning and Research Work Program- Subpart A, SP0020 (042). Kentucky: Frankfurt. Accessed at https://transportation.ky.gov/Planning/Documents/FY%202025%20Work%20Program.pdf. Last accessed September 15, 2024.

recommending all or a majority of these as we realize each measure requires resources to collect relevant data). These performance measures also relate to the issues identified at the first meeting with KYTC staff.

- Progress in transitioning the current risk assessment approach to a multi-hazard, quantitative approach.
- Proportion of projects in each year using a risk-based design approach.
- Proportion of high-risk existing assets for which a detailed adaptation analysis has been conducted.
- Effectiveness of KYTC's organizational structure and leadership in supporting emergency response efforts
- Periodic assessment of KYTC staffing needs in support of the resilience efforts (e.g., need for more GIS staff)
- Proportion of the total length of major roadways having pre-planned detour routes/closure plans (and similar measures for other modes).
- Proportion of critical structures and electronic assets that are hardened against the emerging types of extreme weather threats.
- Existence of updated O&M emergency response plan, including existence of on-call support contracts to provide assistance given the types of disruptions being faced.
- Existence of updated vegetation management and control strategies reflecting changing environmental conditions.
- Incorporation of hazard ratings into KYTC's prioritization processes and decision-making.
- Monitoring the use of resilience factors in allocating non-capital dollars for other KYTC services, not administrative or overhead.
- Incorporation of resilience-related performance measures into KYTC's performance management system.
- Periodic reassessment of the type of asset condition data needed for risk assessment given changes in environmental conditions.
- Number of KYTC staff who have taken resilience-oriented training courses or who have participated in resilience-oriented professional development meetings or workshops.
- Number of KYTC emergency response staff who have taken training courses or who have participated in development meetings or workshops focusing on future climatic and extreme weather challenges.
- Level of coordination among KYTC and other emergency response partner agencies (as determined through after action reports).
- Stated (and written) strategy for including resilience concerns into KYTC's overall communications strategy, and updated on periodic basis.
- Incorporation of resilience topics and concerns in internal communications outreach efforts with KYTC staff; assessment of the effectiveness in terms of staff awareness.
- Incorporation of resilience topics and concerns in communications outreach efforts to key KYTC constituencies; assessment of their effectiveness.

The concept is that this information would be used by KYTC managers to identify where additional effort might be necessary to integrate resilience more effectively into agency decision-making. In addition, it is expected that this information could be used to tell the KYTC “resilience” story to key stakeholders and to the public.

APPENDIX C: ILLUSTRATIVE EXAMPLES OF PERFORMANCE MEASURES AND RESILIENCE OBJECTIVES

Objective: Organize For Success		
	PM: Degree to which the recommendations in the RIP have been implemented.	
		Target: ___ % of the recommendations implemented by the end of year ____; ___% of the recommendations implemented by the end of year ____; ___% of the recommendations implemented by the end of year ____.
	PM: Effectiveness of KYTC's organizational structure and leadership in fostering a more resilience-oriented focus in decision-making.	
		Target: ___% effectiveness as determined by internal survey; ___% effectiveness as determined by external survey.
	PM: Periodic assessment of KYTC staffing needs in support of the resilience efforts (e.g., need for more GIS staff)	
		Target: Assessment of resilience staffing needs conducted every ___ years.
	PM: Level of coordination between RIP and other KYTC plans and program documents.	
		Target: ___% stated coordination as determined through internal survey.
	PM: Level of coordination between RIP and external planning processes/programs.	
		Target: ___% stated coordination as determined through external survey of Minnesota's planning and KYTC partner agencies.
	PM: Number of KYTC staff who have resilience concerns as part of their job description	
		Target: ___% of staff positions
	PM: Number of KYTC staff who have taken resilience-oriented training courses or who have participated in resilience-oriented professional development meetings or workshops.	
		Target: At least ___ KYTC staff per year participating in such training, professional development meetings, or workshops.
Objective: Improve Resilience-related Communications		
	PM: Stated (and written) business case for why resilience concerns need to be part of KYTC's mission, goals, and objectives; and supported by key constituencies.	
		Target: Written business case and updated every ___ years.
	PM: Stated (and written) strategy for including resilience concerns into KYTC's overall communications strategy, and updated on periodic basis.	
		Target: Written strategy exists and updated every ___ years.

	PM: Incorporation of resilience topics and concerns in internal communications outreach efforts with KYTC staff; assessment of the effectiveness in terms of staff awareness.	
		Target: Assessment of the effectiveness of internal communications efforts every ___ years. Assessment to be based on internal surveys
	PM: Incorporation of resilience topics and concerns in joint communications efforts with KYTC partner agencies (or creating such joint communications if they do not exist); assessment of their effectiveness.	
		Target: Assessment of the effectiveness of joint communications efforts every ___ years. Assessment to be based on internal and external surveys.
	PM: Incorporation of resilience topics and concerns in communications outreach efforts to key KYTC constituencies; assessment of their effectiveness.	
		Target: Assessment of the effectiveness of resilience communications efforts every ___ years. Assessment to be based on internal and external surveys.
Objective: Increase Understanding of Risks		
	PM: Number of RIP recommendations implemented.	
		Target: Half the recommendations implemented by the end of year ____. The remaining half implemented by the end of year ____.
	PM: Provision of staff capabilities to analyze vulnerability data and conduct risk assessments.	
		Target: Expansion of resilience-oriented staff by __ positions by the end of year ___.
	PM: Progress in transitioning the current risk assessment approach to a multi-hazard, quantitative approach.	
		Target: Adopt a modified approach by the end of year ___.
	PM: Implementation of data collection and analysis recommendations in the RIP report and in cooperation with partner agencies in support of such an approach.	
		Target: Half the recommendations implemented by the end of year ____; the remaining half implemented by the end of year ____.
	PM: Number of KYTC planning, environmental, and capital programming staff who have taken training courses or participated in professional development meetings or workshops focusing on risk assessment.	
		Target: At least ___ KYTC staff per year participating in such training, professional development meetings, or workshops.
Objective: Strengthen Emergency Response		
	PM: Effectiveness of KYTC's organizational structure and leadership in supporting emergency response efforts	
		Target: ___% effectiveness as determined by internal survey; ___% effectiveness as determined by external survey.
	PM: Level of coordination among KYTC units involved in emergency response.	

		Target: ___% stated coordination as determined through internal survey.
	PM: Level of coordination among KYTC and other emergency response partner agencies.	
		Target: ___% stated coordination as determined through external survey of KYTC partner agencies.
	PM: Implementation of (or updating) KYTC's use of post-event data obtained from KYTC staff and emergency response partner agencies in assessing the effectiveness of future emergency response efforts and possible use in risk assessments.	
		Target: ____% of post-event data being used to assess effectiveness of emergency response by the end of year ____; ____% of post-event data being used in risk assessments by the end of year ____.
	PM: Number of KYTC emergency response staff who have taken training courses or who have participated in development meetings or workshops focusing on future climatic and extreme weather challenges.	
		Target: At least ___ KYTC emergency response staff per year participating in such training, professional development meetings, or workshops
Objective: Enhance Operations and Maintenance Activities		
	PM: Proportion of the total length of major roadways having pre-planned detour routes/closure plans (and similar measures for other modes)	
		Target: Increase the proportion of the total length of major roadways having pre-planned detour routes/closure plans by __% by the end of year ____
	PM: Proportion of the total length of major roadways having detour route signage (or plans for rapid reaction temporary signage).	
		Target: Increase the proportion of the total length of major roadways having detour route signage (or plans for rapid reaction temporary signage) by __% by the end of year ____
	PM: Proportion of critical structures and electronic assets that are hardened against the emerging types of extreme weather threats.	
		Target: Increase the proportion of critical structures and assets by ___% by the end of year ___
	PM: Existence of updated O&M emergency response plan, including existence of on-call support contracts to provide assistance given the types of disruptions being faced	
		Target: O&M response plans updated at least every ___ years
	PM: Existence of updated vegetation management and control strategies reflecting changing environmental conditions	
		Target: Vegetation management and control strategies updated at least every ___ years
	PM: Existence of updated KYTC Continuation of Operations Plan (COOP) that reflects the latest understanding of the changing weather-related stresses and system risks	
		Target: Updated KYTC COOP at least every ___ years
Objective: Consider the Impact of Changing Environmental Conditions During Project Development		

	PM: Updated guidance incorporated into project development standard operating procedures and design standards reflecting changing environmental conditions	
		Target: Incorporate and update every ____ years risk-based analysis procedures and recommended design alternatives. Initial incorporation to be completed by the end of year ___.
	PM: Proportion of projects in each year using a risk-based design approach.	
		Target: Increase the proportion of projects in each year using a risk-based design approach by __% by the end of year ____.
	PM: Proportion of design projects in each year that consider future environmental risks.	
		Target: future environmental risks of the changing environment by __% by the end of year ____.
	PM: Proportion of design projects in each year whose final design is influenced by future environmental risks.	
		Target: Increase the proportion of design projects in each year whose final design is influenced by future environmental risks by __% by the end of year ____.
	PM: Proportion of high-risk existing assets for which a detailed adaptation analysis has been conducted.	
		Target" Increase the proportion of high-risk existing assets for which a detailed adaptation analysis has been conducted by __% by the end of year ____.
	PM: Number of KYTC project development staff who have taken training courses or who have participated in development meetings or workshops focusing on future climatic and extreme weather challenges and how to handle in project development.	
		Target: At least ___ KYTC project development staff per year participating in such training, professional development meetings, or workshops.
Objective: Integrate Future Environmental Risks Into Asset Management		
	PM: Incorporating resilience and RIP concerns into TAMP updates.	
		Target: The 2026 TAMP will reference and include resilience concerns, strategies, priorities, and needs.
		Target: Resilience-specific metrics will be incorporated into the 2026 TAMP.
	PM: Enhancing KYTC capabilities in providing risk-based information for project decision-making.	
		Target: Develop quantitative risk models with consistent results of "future damage cost risks" across all vulnerable asset types by the end of year ____.
		Target: Continue the development of the current flood-focused dataset that will allow KYTC staff to assess changes in flood exposure for past extreme precipitation data. Dataset will be completed by the end of year ____.
		Target: Develop quantifiable hazard-to-impact relationships for assets considered especially at risk. Include in a catalogue of such relationships for use by KYTC staff. Use the current effort at developing flood/overtopping/damage relationships as a model for doing so for other asset types and hazards. Such relationships will be developed by the end of year ____ for asset types of _____;

		developed by the end of year ____ for asset types _____; and by the end of year ____for asset types _____.
		Target: Develop a menu of life-cycle costs for the types of assets likely to be disrupted by extreme weather and natural hazards by the end of year ____. Update as needed as new data is collected on the costs associated with system disruptions and new information is available on the magnitude and scale of future hazards.
		Target: Strengthen the linkage between asset management and O&M by developing process for integrating impacts of O&M planning and capital funding impacts on O&M by the end of year ____.
		Target: Develop a formal process of enhancing communications among resilience-related units and staff in KYTC by the end of year ____.
	PM: Number of data collection and analysis recommendations in the RIP report in support of integrating resilience concerns more effectively in asset management	
		Target: Half the recommendations implemented by the end of year ____. The remaining half implemented by the end of year ____.
	PM: Enhancing resilience capabilities of asset management staff.	
		Target: __% of job descriptions in the asset management unit that have resilience as part of the description.
		Target: __% of new District hires in asset management specialties exposed to training and professional development activities by the end of year ____.
Objective: Enhance Consideration of Resilience Needs in Project Programming		
	PM: Incorporation of hazard ratings into KYTC's prioritization processes and decision-making.	
		Target: Hazard ratings formally included in KYTC's prioritization by the year ____.
	PM: Incorporation of risk-oriented criteria into KYTC's prioritization processes and decision-making.	
		Target: Risk-related criteria formally included in KYTC's prioritization by the year ____.
	PM: Progress of resilience-oriented projects identified in the RIP and by KYTC in other processes.	
		Target: __% of the projects completed by the year ____; __% of the projects completed by the year ____.
	PM: Proportion of KYTC annual capital program having resilience characteristics incorporated.	
		Target: __% of the projects (or funding) having resilience characteristics purposely incorporated into the project design (determined through surveys of project development staff).
	PM; Monitoring the use of resilience factors in allocating non-capital dollars for other KYTC services, not administrative or overhead.	
		Target: __% of non-capital budget considering resilience factors by the year ____.
	PM: Perceived importance of resilience factors in establishing investment priorities.	

		Target: __% of KYTC staff perceiving resilience as being important in establishing priorities (determined through surveys of project development staff).
Objective 9: Monitor and Manage System Performance		
	Enhancing the Resilience Monitoring System	
	PM: Incorporation of resilience-related performance measures into KYTC's performance management system	
		Target: Candidate performance measures are selected and incorporated into KYTC's performance management system by the year ____.
	PM: Adoption of performance monitoring data collection and use recommendations identified in the RIP.	
		Target: Selected recommendations are implemented by the year ____.
	PM: Given the continuing updates in knowledge and understanding of changing environmental conditions, establishing and using a formal re-evaluation process of the resilience performance measures.	
		Target: A re-evaluation process is in place with such re-evaluations occurring every ____ years.
	PM: Incorporation of the results of resilience performance monitoring in KYTC reporting and in the communications strategies.	
		Target: Results are incorporated into KYTC reporting and communications no later than ___ year after adoption of the resilience performance measures.
	Asset condition	
	PM: Collection of data on asset condition identified in the RIP as needed for risk assessment.	
		Target: Recommended data collection implemented by the year ____.
	PM: Periodic reassessment of the type of asset condition data needed for risk assessment given changes in environmental conditions.	
		Target: Reassessment process in place by the year ____.
	Safety	
	PM: Number of injuries attributable to extreme weather events on the KYTC system per year, normalized by the number and intensity of weather events.	
		Target: Reduce the number of injuries attributable to extreme weather events on the KYTC system by ___% by the year ____, normalized by the number and intensity of weather events.
	PM: Number of deaths attributable to extreme weather events on the KYTC system per year, normalized by the number and intensity of weather events.	
		Target: Reduce the number of deaths attributable to extreme weather events on the KYTC system by __ % by the year ____, normalized by the number and intensity of weather events.
	PM: Number of injuries attributable to extreme weather events on the KYTC system per year, normalized by the number and intensity of weather events.	

		Target: Reduce the number of deaths attributable to extreme weather events on the KYTC system by __ % by the year ____, normalized by the number and intensity of weather events.
	Service continuity	
	PM: Number of facility closures (or capacity limitations) attributable to damage from flooding, extreme heat, or landslides/rockfalls (separate measure for each hazard) on the KYTC system per year, normalized by the number and intensity of events. Break down by facility type and whether a full closure or just a capacity limitation. Also, specifically track the results for facilities designed with future climate projections vs. those that are not.	
		Target: Reduce number of facility closures (or capacity limitations) attributable to damage from flooding, extreme heat, or landslides/rockfalls on the KYTC system by __% by the year ____, normalized by the number and intensity of events (break down by facility type and whether a full closure or just a capacity limitation).
	PM: Average duration of facility closures (or capacity limitations) attributable to impacts from extreme weather events on the KYTC system per year, normalized by the number and intensity of events (break down by facility type, cause of event [flooding, landslide/rockfall, etc.], and whether a full closure or just a capacity limitation).	
		Target: Reduce average duration of facility closures (or capacity limitations) attributable to damage from extreme weather events on the KYTC system by __% by the year ___, normalized by the number and intensity of events (break down by facility type, cause of event [flooding, landslide/rockfall, etc., and whether a full closure or just a capacity limitation
	Maintenance/repair costs	
	PM: Maintenance/repair costs attributable to various hazards (flooding, extreme temperatures, landslides, etc.) and asset types (breakout by asset-hazard combo).	
		Target: Reduce maintenance costs __% by the year ___ for asset-hazard combinations, normalized by the number and intensity of events.

MEMO

TO: Tracy Nowaczyk (KYTC)

FROM: Elizabeth Farc (WSP), Chris Dorney (WSP), and Mike Meyer (independent consultant)

SUBJECT: Task 1.4: Potential Resilience Strategies

DATE: March 14, 2025

INTRODUCTION

This memo presents an overview of potential resilience strategies (including nature-based solutions) for KYTC roadway infrastructure, given the types of hazards identified in KYTC's Resilience Improvement Plan (RIP) and from internal agency feedback received during Task 1.3. This memo focuses on general resilience strategies that address the most frequently encountered and impactful of these hazards, including:

- Extreme high temperatures
- Flooding and excessive moisture
- Landslides
- Wildfires
- High winds
- Winter storms

The strategies build on work undertaken by WSP for the National Cooperative Highway Research Program (NCHRP), Federal Highway Administration (FHWA), and other state departments of transportation (DOTs). Recommended strategies include both physical improvements (including nature-based solutions) and operations and maintenance (O&M) actions that can reduce asset downtimes.

The memo is organized as follows. The next section provides an overview of different types of resilience strategies. The following section then discusses specific strategies for each of the hazards listed above. Resilience strategies under each hazard are generally grouped by asset type.

OVERVIEW OF RESILIENCE STRATEGIES

A key part of KYTC's success in bolstering the transportation system's resilience to extreme weather lies in the implementation of resilience enhancements to projects already in the project pipeline and, as funding permits, the delivery of dedicated resilience projects. Understanding the types of resilience strategies that KYTC may implement in response to various natural hazards provides valuable insights for developing such projects. This memorandum aims to bring together various generalized resilience strategies into one place for project teams to reference and consider for application in their work.

The strategies described in this document were chosen to address the various natural hazards and design challenges common to and impactful to Kentucky. Based on input provided during the facilitated leadership discussions, KYTC already has design strategies in place for protection against some hazards, such as retrofitting bridges in western Kentucky against seismic hazards. The project descriptions presented are not intended to list all the design approaches KYTC might use for various situations; each project design will be specific to a particular location and its design parameters. However, they are intended to provide KYTC staff and partners with an understanding of the options they might consider for use on their projects.

There are various helpful ways to categorize resilience strategies. Two schemas are used in this document and indicated by icons next to each applicable strategy in the ***Resilience Strategies*** section. The first schema considers the overarching philosophy in each resilience strategy. Categories in this schema include (1) asset protection, (2) accommodation of environmental stresses, and (3) removal/relocation of an at-risk asset out of harm's way (i.e. managed retreat). The second schema categorizes the strategies into engineered strategies versus nature-based solutions. ***Figure 1*** shows the icons used to classify strategies in subsequent sections of this document. Note that no icon is used to denote engineered strategies; all capital improvement actions not denoted with the nature-based solution icon are considered engineered strategies.

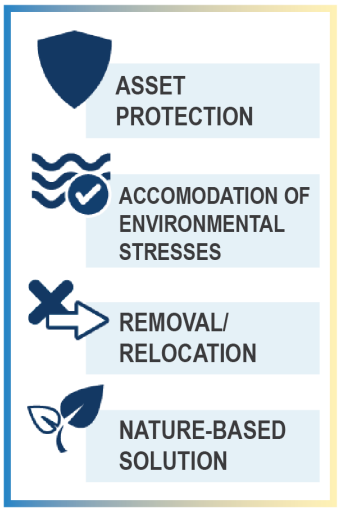


Figure 1: Category Icons

The next two sections provide background on how each of these two different strategies is defined. After this, some important concepts that apply to any resilience strategy are discussed.

ENGINEERED STRATEGIES

Engineered strategies (sometimes called "grey infrastructure") are physical changes to an asset or the provision of protective enhancements in the surrounding environment aimed at minimizing damage to the asset. Such strategies are not uncommon to state DOTs as they are often part of project conceptual designs. Engineered strategies can be applied to all types of hazards, but in Kentucky, engineered strategies are particularly relevant for minimizing impacts from landslides/rockslides, flooding, extreme temperatures, and high winds.

Engineered strategies have the following characteristics:

- Designs are based on an underlying understanding of the external forces that will act upon an asset and of the design concepts that can be applied to counteract or minimize the impacts such forces have on the asset itself. For example, engineered strategies aimed at stabilizing slopes to avoid landslides depend on understanding the factors that contribute to unstable conditions, and the potential for different strategies to minimize such instability.
- Although site-specific factors will influence the specific nature of an engineered strategy, many designs follow basic principles and approaches found in engineering design manuals and design guidance. For example, the U.S. Army Corps of Engineers (USACE) has developed numerous guides on the design of retaining walls, embankments, levees, and other structures designed to protect nearby assets. The same is true for the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO).
- Many state DOTs have adopted an approach toward roadway design that reflects the community and natural environment within which the road is to be constructed. Called by many different names (e.g., context-sensitive solutions, flexible solutions, etc.), these strategies include efforts to modify a design to better fit into the human and natural environment. It is important to note that often such designs run up against a desire for a more cost-efficient design during the value engineering process, whose major goal is to enhance the value while minimizing costs.
- Many nature-based solutions (described below) also include engineered strategies as part of the overall design. These hybrid solutions are quite common. Thus, it's important to recognize that it's often not an "either or" approach when it comes to engineered strategies and nature-based solutions.

NATURE-BASED SOLUTIONS

A design philosophy being used by many communities involves utilizing environmental systems to reduce natural hazard impacts on transportation assets. Resilience strategies fitting this description are referred to herein as nature-based solutions (other terms commonly used include Low Impact Design [LID], natural infrastructure, green infrastructure, natural and nature-based features, engineering with nature, building with nature, and working with nature). Nature-based solutions are actions to protect, sustainably manage, or restore natural or modified ecosystems to address societal challenges, simultaneously providing benefits for people and the environment."[1] These strategies have, to date, been strongly encouraged within the federal government's *Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation* (PROTECT) Program. As mentioned above, the concept of nature-based solutions includes hybrid solutions that integrate engineered aspects into restored or created natural features. In many instances, combinations of nature-based features with engineered systems may yield benefits beyond those achieved individually. Wherever appropriate, nature-based solutions are presented for each of the hazard types covered in this memorandum.

Nature-based solutions, even more so than other resilience strategies, are best considered early in planning and design with input from decision-makers and stakeholders. Opportunities for these strategies increase greatly when discussions begin early and include relevant participants. One reason for this is that right-of-way limitations can be a significant barrier for implementing nature-based solutions. For example, preventing flooding at a culvert by expanding the upstream floodplain width to accommodate more water retention may require coordination with surrounding property owners. KYTC will need to engage with relevant partners early to navigate jurisdictional challenges. Also, staff not traditionally involved in the early stages of project development like environmental specialists who are specifically trained in natural infrastructure planning and design, might need to be consulted and involved when implementing these strategies.

KYTC can proactively establish mechanisms to identify and leverage the most advantageous opportunities for integrating nature-based solutions. It is advisable to ensure that appropriate information and decision-making frameworks are in place to facilitate the consideration and implementation of these strategies. Note that there may be a need to carefully consider the timing of implementation of the nature-based solutions to align with timeframes of the natural systems.

National and state practices have led to some important lessons with respect to using nature-based solutions in mitigating natural hazards, including:

- Nature-based features may mitigate hazards under low to moderate intensity events whereas engineered strategies can be more protective during high intensity events. As discussed above, a hybrid approach may be most beneficial in certain cases.
- The structural design of hybrid approaches, the choice of natural materials, and the ecological context and requirements are important to consider carefully. When combining engineered strategies with nature-based solutions, it is recommended that the design of the engineered components be proportionally scaled to account for the benefits provided by the nature-based components. Additionally, it is important to select the appropriate materials and design the nature-based components to be consistent with the surrounding ecology to avoid unintended negative consequences. Factors such as fill materials, vegetation with respect to the setting and elevation, and the placement of the structures will dictate system performance. It's worth considering including environmental

[1] FHWA. 2019. Implementation Guide on Nature-Based Solutions for Coastal Highway Resilience. Accessed from https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/green_infrastructure/implementation_guide/#toc18511913. Last accessed March 13, 2025

specialists in the design process to make sure that the designed system matches the local ecology and enhances habitat value and function.

- Proactively preserving natural features that already offer resilience benefits is valuable. Natural systems already play an important role in protecting built infrastructure. Transportation practitioners might not consider the protection provided by natural features until the systems begin eroding or become otherwise damaged. Often, engineered infrastructure solutions are implemented to fill the gap. Preservation of natural features may be more cost-effective than engineered strategies; maintaining the health of natural systems can allow them to continue to provide protection with little additional cost or effort.
- Nature-based solutions can decrease the environmental impact of projects (compared with engineered strategies) while also offering a suite of co-benefits. Thereby, nature-based solutions can also be used to meet multiple agency objectives. When all this is accounted for, nature-based solutions can prove to be more cost-effective than engineered strategies in certain situations.
- Nature-based solutions need to be monitored over time as part of an adaptive management program (see below). As with other strategies, nature-based solutions may require actions to maintain the long-term functioning and performance of the system. Adaptive management entails revisiting the project and making iterative adjustments over time as conditions change. Consistent monitoring of the performance provides key information to enable the department to identify potential problems and make modifications over time. Resilience performance management recommendations made as part of this project are found in Task 1.3.3 Memorandum.

KEY CONCEPTS COMMON TO ALL RESILIENCE STRATEGIES

There are some key concepts to keep in mind with respect to all resilience strategies. Two that we will focus on here include adaptive management and use of resilience benefit-cost analyses. Adaptive management is an important concept to consider with any of the strategies discussed in this memorandum. This concept involves implementing a series of resilience actions over time to allow for adjustments based on new circumstances or new information on anticipated conditions, rather than predetermining a set of investments based solely on current knowledge (which is often limited and has a wide range of uncertainty). This approach may involve tracking information to identify potential trigger points that signal when a decision is necessary and establishing decision-making processes to support effective solutioning. KYTC is currently partnering with the Kentucky Transportation Center (KTC) on a research project that will support use of adaptive management strategies.

Another topic to consider for any of the resilience strategies is how to choose amongst them when multiple strategies could be applied to the same project. Likewise, how to choose the right level of protection within each strategy? Decisions such as these can be addressed through performing benefit-cost analyses (BCAs) of the various strategies and their protection levels. For these assessments, benefits are defined as the costs avoided (to KYTC and, if desired, system users and the broader economy) from undertaking the resilience investments. Costs encompass the incremental price of constructing the resilience features and maintaining them. Resilience BCAs, therefore, assess the cost-effectiveness of different adaptation strategies and protection levels over the lifespan of the asset, helping to determine to what degree, if any, the (typically) higher up-front costs of resilience enhancements will pay off in the long run by reducing risk. It is recommended that KYTC consider implementing tools and procedures to enable efficient use of BCAs to inform resilience decision-making on future projects.

RESILIENCE STRATEGIES

The following section outlines the types of hazards and threats associated with various climate stressors, the potential impacts on the Kentucky transportation system from these stressors, and the resilience actions or strategies that KYTC can consider to mitigate or reduce impacts. Further development of specific design guidance would be needed to implement some of the suggested strategies and approaches described in the following sections. Resilience strategies are grouped by the primary hazard they address starting with extreme high temperatures and proceeding to flooding and excessive moisture, landslides, wildfires, high winds, and winter storms. Where appropriate, the resilience strategies under each hazard are grouped by the asset type they apply to.

EXTREME HIGH TEMPERATURES

Kentucky is expected to experience warmer weather on average in future years including a higher number of days with extreme maximum temperatures. There are four major KYTC asset types/functional areas that might be affected by higher temperatures: (1) pavement design, (2) worker safety, (3) operations assets, and (4) buildings. Strategies for each of these are described in the sections below.

PAVEMENT

Research and many decades of practice have shown high temperatures pose risks to pavement integrity. High temperature impacts to pavements include increased potential for rutting and shoving, increased age hardening of asphalt binder, increased potential for concrete temperature-related curling, and increased risk of pavement blowups due to excessive slab expansion. KTC research found it is not imperative for KYTC to change its approach toward pavement design considering future environmental conditions. However, pavement strategies are included here in case this assessment changes in the future.

Resilience strategies for dealing with higher maximum temperatures and pavement include:

- Increasing the structural adequacy of the pavement layers to improve resistance against fatigue damage and rutting.
- Incorporating design elements, such as shorter joint spacing and use of tied shoulders or widened slabs in jointed plain concrete pavements, and higher steel reinforcement in continuously reinforced concrete pavements, to improve overall performance.
- Selecting more durable materials to withstand the adverse effects of future temperature trends.
- Considering changing to a higher asphalt binder grade.
- Encouraging best practices to improve materials and construction quality.
- Identifying changes to the type and timing of maintenance and repair (M&R) treatments to deliver the desired levels of service at the lowest practicable life-cycle costs.

WORKER SAFETY

Many KYTC workers and contractors spend much of their workdays outdoors, especially construction and maintenance workers. Higher temperatures could create unhealthy work environments in which prolonged exposure to extreme heat could result in dehydration, heat exhaustion, and heat stroke.

The Occupational Safety and Health Administration (OSHA) has provided guidance on heat-related fatalities and illnesses for both outdoor and indoor environments.[2] Some of the strategies for lessening heat-related impacts include:

- Developing a Heat Illness Prevention Plan, including identifying and controlling heat hazards; recognizing early symptoms of heat stress; administering first aid for heat-related illnesses; and activating emergency medical services quickly when needed.
- Examining national and other state heat standards to determine if they could be applied to Kentucky.
- For new workers in the field, considering the following strategies: schedule new workers to work shorter amounts of time working in the heat, separated by breaks in heat stress conditions; give new workers more frequent rest breaks; train new workers about heat stress, symptoms of heat-related illness, and the importance of rest and water; monitor new workers closely for any symptoms of heat-related illness; and use a buddy system not allowing new workers to work alone.
- Adopting policies for KYTC staff and contractors to take more frequent/longer rests to hydrate during dangerously hot days. Providing shaded areas for breaks.
- Providing an air-conditioned facility near construction sites where staff can go to cool off if they feel affected by extreme heat.
- Allowing/encouraging the use of light weight, reflective, and cooler clothing during days with extreme heat.
- Where possible, shifting more work to nighttime hours during the summer.
- Conducting training for all employees on the symptoms of heat-related illnesses and how to respond quickly and effectively.

OPERATIONS ASSETS

Many operations assets (e.g., signals and communications, monitoring, and information systems) contain electronics that are sensitive to high temperatures or affected by power supply disruptions due to excessive demand. Strategies for dealing with these concerns include:

- Examining specifications for operations assets over time to ensure they reflect the changing environmental context relating to higher temperatures.
- Performing regular maintenance checks on cooling devices for electronic equipment (fans, etc.)
- For mission-critical equipment, consider air conditioning or other strategies to mitigate against heat-related failure.
- Provisioning emergency electrical backup for facilities considered critical in case of power outage. In addition, transition to solar energy or other energy sources that do not rely on the electric grid.

BUILDINGS

Buildings and their cooling systems are designed with certain expectations for temperature control in hot weather. Resilience strategies for buildings and extreme heat include:

- Using materials that are highly reflective of light such as white roofing tiles; also consider the use of green roofs (vegetation).
- Providing good insulation and cross ventilation to minimize loss of cool air inside a building.

[2] Occupational Safety and Health Administration (OSHA). Undated. Overview: Working in Outdoor and Indoor Heat Environments, webpage. Accessed at https://www.osha.gov/heat-exposure. Last accessed March 14, 2025.

- Provisioning air conditioning for structures housing sensitive equipment and employees. Most KYTC buildings already feature air conditioning but there may be some that do not.
- Re-evaluating air conditioning load ratings over time. Upgrade systems over time, as necessary.
- Surrounding buildings with trees that will provide shade both the building itself and to the employees working in the building (although it takes time for trees to mature to a point where they can have a strong impact). Other forms of shade such as overhands and window awnings can also be considered.
- For new buildings, consider building placement and location of windows to avoid direct sunlight.

FLOODING AND EXCESSIVE MOISTURE

Kentucky has experienced numerous significant, and damaging, flooding events over the past 20 years. Much of this flooding has caused substantial damage to roads and bridges, although more so to locally and privately owned infrastructure versus the state highway network. However, flooding has caused some disruptions to the state highway network as well. The trend towards more moisture and flood events is expected to continue. Three types of assets are of greatest concern to KYTC with respect to flooding and excessive moisture: (1) at-grade roads/pavement, (2) bridges, and (3) culverts. Resilience strategies for each of these asset types is described below. Following this is a discussion of broader watershed strategies (many outside KYTC right-of-way) that KYTC might consider implementing in collaboration with local communities to mitigate flooding to a wide variety of KYTC asset types.

AT-GRADE ROADS/PAVEMENT

At-grade roads/pavement are some of the most impacted network assets from excessive moisture and flooding. Excessive moisture is primarily a concern for the pavement component of at-grade roads. Damage can ensue when heavy loads are put on a paved surface that is not adequately supported by sufficiently dry, stable ground. Some strategies to deal with excessive pavement moisture include:

- Providing a more stable foundation, such as using chemical stabilization, vertical moisture barriers, and geosynthetic reinforcement for the base, subbase, and subgrade to reduce erodibility, soil plasticity, moisture fluctuations, and shrink-swell potential.
- Improving cross-slope and subsurface drainage systems using a combination of longitudinal, edge and transverse drains, permeable bases, drainage blankets, geosynthetics, and other appurtenances to remove excess moisture and prevent erosion, infiltration, seepage, and loss of structural support and stability.

With respect to flooding (full inundation) of the pavement, impacts could range from minor pavement damage to significant damage to the road foundation (typically due to erosion) requiring complete replacement of the affected road section. Three resilience strategies to mitigate flood impacts to at-grade roads/pavement are armoring, road/bridge elevation, and road removal/relocation. Each of these is described in more detail below.

Armoring

As is suggested by the name, an armoring strategy consists of using durable materials to protect the road embankment from significant erosion. Armoring materials can include rock or gravel, rock-level spreaders (a stepped wall protecting the embankment of external flows), and erosion mats that add tensile strength to the embankment (see **Figure 2**).

Figure 2: Embankment Erosion Mats, Iowa DOT

Road/Bridge Elevation

Some DOTs have reconstructed vulnerable road segments and bridges at higher elevations to account for the risk of future overtopping. Depending on the extent and scope of the road elevation, this strategy could be expensive although it is most likely the most effective strategy for minimizing future overtopping.

Removal/Relocation

In some cases, repeated inundation of roadways has resulted in a collaborative effort to decommission and/or relocate the asset away from the floodplain. This strategy, often referred to as managed retreat, can be very involved, public outreach-intensive, and potentially quite expensive. That said, in some cases, it can be the most sure-fire and cost-effective strategy in the long run for avoiding the impacts from natural hazards.

BRIDGES

For the purposes of this section, bridges will include any open-bottom structure supported on a foundation, whereas any closed-bottom structure (of any span arrangement) is considered as a culvert. Significant differences between bridges and culverts are principally related to (1) the size of the structure, (2) the exposure of the bridge foundation to scour conditions, (3) inclusion of scour protection measures along abutment areas, and (4) the use of piers at bridges. A bridge must be designed to pass a flood of specified frequency/magnitude, often with an additional freeboard (the clearance between the design water surface elevation and the bottom of the bridge) to accommodate uncertainty in the prediction of water surface elevations and/or the possibility of debris in the floodwaters. New bridge foundations are often assessed for scour conditions for a design flood and a more severe check flood condition.

The vulnerability of bridges will change as precipitation patterns shift over time. In the event of increased storm floods, undersized bridges could be washed out, either via enhanced scour and differential settlement of a foundation or washout of a bridge deck from its supports. Other potential impacts could include the washout of abutment protection (resulting in the washout of approach roadways), increased risk of roadway overtopping/inundation (with the potential of stranded vehicles or vehicles swept off flooded roads), closure and detour of roadways, potential damage/breaching of elevated roadway embankments, increased maintenance requirements for debris removal, and increased maintenance needs for the repair of abutment scour countermeasures.

Table 1 shows strategies for increased bridge structural resilience. Each of these are described further in the sections below.

Table 1: Resilience Strategies by Hazard Type, Bridges

Resilience Strategies	Applicable Hazards		
	Precip./Flooding	**Scour/Erosion**	**Drought**
Enhanced Superstructure Design	+++	+++	
Increased Freeboard Clearance	+++		
Rip Rap, Lining, and Foundations		+++	
Channel Design/Monitoring	+++	+++	++

+++ Major potential contribution to reducing hazard impacts

++ Medium potential contribution to reducing hazard impacts

+ Minor potential contribution to reducing hazard impacts

Enhanced Superstructure Design

--Precipitation/Flooding -- Scour/Erosion

Bridge superstructures (deck, girders, railing, etc.) can be designed to withstand stream pressures and debris traveling at high velocities—as experienced in severe floods, mudflows and landslides—to increase the structure's ability to absorb or deflect impacts during a flood. In many cases, increasing the span of a bridge is a good strategy for decreasing vulnerability of the bridge. It is, however, the most-costly adaptation option. Increasing the span of bridges addresses vulnerability concerns related to freeboard and overtopping by decreasing the upstream depth of flooding (if not otherwise affected by another downstream backwater limitation), decreases scour concerns by lowering erosive velocities and flow depths, and decreases stresses on scour countermeasure/abutment protections by, again, lowering velocities.

That said, this option is often not considered if the span increase introduces a bridge pier into the design. If not already otherwise considered for the structure, the inclusion of a pier would represent additional new vulnerability risks for the structure, primarily due to the need to protect the new structural element. Before recommending a new pier for widening, consider other adaptation options. Furthermore, allowing more water to pass through could increase flooding downstream and open a DOT up to legal issues.

Except in some special scenarios, bridges are not designed for lift-off (a rare event where a part of a bridge, usually the superstructure, can lift off from its supports due to water flow and/or buoyancy). With high velocities, the bridge parts taken downstream are likely to cause additional damage from being tossed around by currents and meandering of the channel or river. Some structure types, such as many precast girders, are prone to lift off as the superstructure is not attached to the substructure. One measure to prevent superstructure lift-off is to add tiedowns that provide positive connectivity between superstructure and substructure and prevent lift-off as the water rises and the flow velocities increase. The provision of air vents on the deck can also limit decks becoming buoyant. These measures should be considered for bridges that have a strong potential for deck overtopping.

Increased Freeboard Clearance

-- Precipitation/Flooding

Increasing the standard for minimum freeboard clearance will provide a larger opening for water to flow through, thus reducing the flow velocity and decreasing the probability of damage to the bridge. In some

cases, where bridge locations are particularly prone to high flood levels or where the likelihood of significant debris flow is high, structural design may call for more than the minimum freeboard.

Increased levels of bridge freeboard will add resiliency to a bridge by allowing for increased flow depths that do not impact the bridge superstructure/overtop the bridge deck. Additionally, increased freeboard will make a bridge structure more resilient to debris flow conditions, such as may be encountered in watersheds affected by wildfires. However, freeboard increases alone will not provide a notable increase in the structure resilience against foundation scour impacts or against abutment scour and the possible loss of approach roadway fill. In addition, raising the freeboard could increase flooding downstream, opening a DOT up to legal challenges.

Rip Rap, Concrete Lining, and Deep Foundations

--Scour/Erosion

Scour and erosion are chief concerns in areas where high frequency and high levels of flooding are observed or probable. Mitigation efforts are available for erosion and scour, such as rip rap (loose rock, concrete blocks, or other material placed along shorelines, slopes, and bridge foundations to protect from scour and erosion) or concrete channel lining, to shield bridge foundations from the eroding effects of moving water. The faster the current, the larger the rip rap must be.

In addition, deep foundations, such as drilled shafts or piles, can be used to mitigate the effects of scour and erosion. The deep foundations are designed to extend beyond the anticipated scour depth to provide support in material not susceptible to scour. Shallow foundations, such as spread footings, should be avoided in areas prone to scour unless the footing is sufficiently embedded in material not prone to scouring. Increased foundation depths and increased abutment scour countermeasure protection are strategies to help increase a structure's resilience against increased flood depths and velocities. These modifications could be combined with increased bridge freeboard to provide similar levels of resilience to that obtained by increasing the span of a bridge.

Channel Design and Monitoring

--Precipitation/Flooding *--Scour/Erosion* *--Drought*

Other measures, such as widening or increasing the cross-section of the channel at the bridge location, can help to mitigate impacts of higher flood levels and more frequent events by slowing the velocity of the water flow. Vegetated, sloped banks in channels may also help to slow erosion and absorb increased inundation.

Longer drought periods may be put to beneficial use by ensuring inspections are aligned with seasonal conditions in a way that allows inspectors to evaluate bridge foundations when the river or channel bottom is dried up. Maintenance and implementation of scour mitigation measures can be scheduled during times of lower water levels before scouring becomes unmanageable.

Floodplain Culverts

--Precipitation/Flooding *--Scour/Erosion*

As defined by the Minnesota Department of Natural Resources, floodplain culverts are "set under a road, trail or other infrastructure that crosses a floodplain to enhance floodplain conductivity. They are typically designed to allow runoff to remain in the natural floodplains during a flood instead of confining flow to a main channel culvert or bridges as often found in traditional culvert design."[3] In conjunction with bridge designs,

[3] Minnesota Department of Natural Resources.2017. Floodplain Culvert Fact Sheet, Webpage. Accessed at https://files.dnr.state.mn.us/eco/streamhab/geomorphology/floodplain-culvert-factsheet.pdf. Last accessed March 14, 2025.

floodplain culverts can reduce the amount of water flow passing underneath the bridge, thus minimizing potential impacts of bridge scour. Although of benefit to bridges, floodplain culverts do not have to be constructed adjacent or near the bridge itself. The location of the culverts is determined by the land topography and the hydraulic characteristics of rivers, streams, and expected flooding conditions.

CULVERTS

Culverts are included in nearly every highway facility contained in the DOT inventory. Culverts are generally viewed as minor structures,[4] however, the prevalence of culverts combined with increased rainfall can be anticipated to affect roadways throughout the state in a major way. Inadequately sized culverts could cause road overtopping/inundation, increased maintenance requirements for sediment and debris removal, and even roadway failure/breaching if the culvert is washed away or collapses.

Wildfire impacts on watershed and the associated vulnerability of culvert systems are of concern for roadways in wildfire-prone areas of the Commonwealth. Wildfires are known to have strong influences on peak storm flows and debris flow conditions within streams. The impact of wildfires on culverts varies based on the fire's size and severity, as well as the size of the contributing drainage area. It is essential for engineering practitioners to understand these potential risks when evaluating the cost-benefit analysis of different design options.

Some resilience strategies that could be considered for culverts include:

Armoring

--Precipitation/Flooding *--Scour/Erosion*

Armoring around culvert outfalls and the downstream side of the associated embankment is a common resilience strategy. Specific strategies include adding wingwalls and/or adding outfall scour protection such as adding an apron at the outfall location. The intent of both is to minimize erosion that could undermine the effectiveness of the culvert.

Increased Hydraulic Capacity

--Precipitation/Flooding *--Scour/Erosion*

Increasing hydraulic capacity is another important resilience strategy for culverts. Hydraulic capacity could be increased by changes in culvert materials (concrete replacing corrugated metal), culvert shapes (boxes replacing pipes), pipe sizes, and number of pipes. Other factors driving hydraulic capacity (including culvert slope, channel bed roughness, and tailwater condition) are a function of the stream/river systems and not readily modified as part of a culvert replacement program. Under some conditions, an existing undersized culvert may provide the attenuation of peak flood flows to areas downstream of the structure. In these cases, increasing culvert hydraulic capacity could result in increased downstream flooding.

Several states are lining old culverts with new materials that cut down on the friction of water flow through the culvert. By so doing, the culvert can handle higher flow volumes.

Typically, the replacement of a culvert is anticipated to occur as part of a larger roadway reconstruction project. In such cases, culvert replacement costs would likely not represent a substantial impact to an overall roadway reconstruction budget. However, in some cases, state DOTs have found that the existing and potential new culvert designs are not able to handle the expected water flow at that location. In such cases, culverts have been replaced with small bridges, which would increase the cost of the project substantially.

[4] KYTC. Drainage Manual, DR 600 Culverts, https://transportation.ky.gov/Highway-Design/Drainage%20Manual/DR%20600%20Culverts.pdf.

The culvert design process should consider the benefits, costs, and consequences of upsized culverts to account for future changes in flows. Unintended consequences of upsized culverts could include increases in routine inspection requirements for large culverts that fall under the requirements for routine bridge inspections.

COMMUNITY-BASED STRATEGIES

Community-based strategies focus on those strategies that are the responsibility of local governments, for example, requirements and guidelines incorporated into zoning laws. Two major categories of community-based strategies are often found in practice: developer/owner-focused strategies that require a property to incorporate flood-related mitigation actions, and design practices that the community itself can incorporate into infrastructure design.

Develop/Owner-focused Flood Mitigation Strategies

-- Precipitation/Flooding

A community's master planning and zoning ordinances provide important leverage over the characteristics of a development's footprint and design. For example, a master plan could identify specific areas of a community that require special considerations given the potential for future flooding. For such areas, a zoning ordinance could include flood-proof development design specifications, standards on impervious surfaces, compensatory storage, and the need for multi-purpose water retention facilities.

Community Infrastructure Design Guidelines/Specifications

--Precipitation/Flooding

Some of the same requirements/guidance that are part of a community's zoning ordinance can be applied to the design of its own infrastructure. For example, design specifications relating to impervious surfaces, retention/storage ponds, drainage systems, and enhanced storm management designs can all contribute to better management of flood events. KYTC can play an important supporting role in fostering community strategies for enhanced flood management.

WATERSHED STRATEGIES

The types of strategies included in this category are not often KYTC's responsibility because the drainage area for water flows leading to its facilities are typically the responsibility of other governments or private citizens. Nonetheless, they are worth considering in partnership with others as they can be highly effective with several co-benefits.

Floodplain Conservation/Preservation

The most efficient and inexpensive natural infrastructure strategy for riverine flooding protection is often floodplain conservation and preservation. Here, an existing natural floodplain is maintained in place to allow for continued delivery of ecosystem services such as flood mitigation. When undisturbed, natural riverine floodplains act as a bathtub to absorb the overflow during floods. These natural floodplains are often inland wetland ecosystems, such as freshwater marshes, swamps, bogs, and fens. Generally, wetlands are an effective option for reducing disaster risk in riverine environments in which semi-aquatic plants slow down the flow of floodwaters, soak them up, and hold soil in place. Because conservation and preservation is a relatively passive strategy that does not involve new construction, there is relatively little cost. There may be an upfront cost to purchase the land, and some level of maintenance involved (e.g., regular clean-ups and management of invasive species). However, the avoided costs from mitigating flood losses are generally worth these inputs.

Restoration of Inland Wetlands

In areas that have already undergone development, restoring historic wetland ecosystems or creating new wetland ecosystems can bring the same benefits as conservation and preservation. Co-benefits include biodiversity, carbon sequestration, and recreational benefits. Wetlands are diverse ecosystems, supporting a wide range of species. Because they can trap sediment and pollution, wetlands can also improve water quality. Having natural areas such as wetlands in communities can provide opportunities for outdoor recreation (e.g., bird watching) and create aesthetically pleasing landscapes. However, because this is a more active strategy that adds natural infrastructure, it is generally more expensive and labor-intensive than conservation and preservation. Both approaches—conserving existing ecosystems or creating new ones—can carry the same flood protection benefits as well as co-benefits.

Flood Setbacks

The use of floodplain ecosystems and wetlands can be combined with the more general risk mitigation strategy of flood setbacks. Flood setbacks establish a minimum vertical and/or horizontal distance between river channels and infrastructure, with the intention to keep the infrastructure out of a likely flood zone. The setback area between the river and the infrastructure can be a natural floodplain, achieving the benefits outlined above and protecting the nearby infrastructure from flooding.

Bank Vegetation and Seeding

On a smaller scale than whole ecosystems, bank vegetation and seeding can introduce natural infrastructure along riverbanks to achieve similar benefits. This strategy involves planting native river plants along riverbanks, which can protect against erosion and decrease the magnitude of floods. The plant roots hold soil in place, while the plants themselves can trap sediment. The plants can also slow the flow of floodwaters. Installing bank vegetation can bring co-benefits like those from the use of natural floodplain ecosystems, including carbon sequestration, increased biodiversity, and improved aesthetics. This is also a relatively inexpensive strategy, with costs largely being incurred during installation. Maintenance generally involves regular monitoring to ensure that the plants are still healthy and in place and to remove invasive species, if needed.

In-Stream Structures

Another strategy to prevent erosion along riverbanks is to install in-stream structures, such as boulders and riffles, to divert water flow and reduce stream velocity. Boulders can lead to riverbed scour, which creates deeper pockets of water, thus reducing velocity in that area. Rock riffles reduce slope grade, which also reduces velocity. In addition, both boulders and riffles can improve fish habitat: boulders can create protected areas for fish, while riffles can increase downstream oxygen levels. These strategies are generally low-cost and low maintenance: once installed, management largely includes periodic inspections and relocations, if necessary.

Channelization

The most intensive strategy for mitigating riverine flooding is channelization. Digging a new channel creates an additional passage, thereby increasing the carrying capacity of the river and diverting flow from the main watercourse. Channelization allows for more water to run through the river (instead of out and above during high-volume events) without disrupting the general river flow. Additional benefits from constructing relief channels include habitat creation and enhancement and improved sediment transport.

Bioswales, Vegetative Swales, and Bioretention Ponds

Bioswales, vegetative swales, and bioretention ponds are a class of natural infrastructure strategies that mitigate stormwater flood impacts by serving as an absorbent catchment for the stormwater. The plants act to attenuate water flows and hold soil in place, while the permeable ground cover allows infiltration into the soil and, possibly, recharge into the water table. The main difference among the strategies in this class relates to their physical structure: bioswales and vegetative swales have milder slopes, while bioretention ponds are deeper and meant to hold small bodies of water. The two categories can work in tandem, with the swales conveying water into the ponds.

Bioswales, vegetative swales, and bioretention ponds have proven to be effective strategies. For example, a 13-foot swale can reduce about one-quarter of total rainfall runoff. They are also cost-effective and are among the least expensive strategies per volume of runoff treated. Bioswales, vegetative swales, and bioretention ponds can also catch and break down pollutants in stormwater, such as heavy metals.

Trees

Trees can also help mitigate the impact of stormwater. Trees planted near transportation infrastructure can intercept and absorb the stormwater through their leaves and roots, thereby decreasing the volume of water. Tree roots also hold soil in place and prevent erosion. Key considerations in implementing trees as stormwater management strategies include species selection, planning conditions, and maintenance. When successfully installed, trees can have a variety of co-benefits, including improved air quality, enhanced habitats, mitigation of extreme heat (and therefore, decreased cooling energy usage), and improved aesthetics. On the other hand, they can also increase the debris load on roads after windstorms and ice storms.

LANDSLIDES

Different types of landslide movements occur in Kentucky, with the most common classifications being earth flows, debris flows, debris slides, rockslides, and rockfalls:

- An earth flow occurs when fine-grained soils cohesively flow down a moderately steep slope. These types of slides are typically initiated by periods of prolonged rainfall. Earth flows are slow moving, normally only fractions of an inch per day.
- A debris flow is characterized by coarse-grained soils that are non-cohesive. These are usually caused by periods of intense rainfall following a period of less-intense precipitation, or by rapid snow melt. These flows move quickly, travel long distances, and can make devastating impacts to infrastructure.
- A debris slide is made up of coarse-grained soil that occurs on extremely steep slopes. These slides have a greater mass than debris flows and can move at a rate of feet per week or faster. A heavy rainstorm or series of storms may trigger debris slides.
- A rockslide is a landslide made up of moving bedrock that occurs on relatively steep slopes. These slides can vary greatly in size and can be triggered by many different factors.
- A rockfall is caused when large boulders and rock masses become detached from a steep slope. Where slopes are made of hard and fractured rock, rockfalls can be extremely dangerous. Heavy rain, earthquakes, and frost wedging can trigger these types of landslides.

Table 2 shows the types of hazards and their potential contribution to landslides.

Table 2: Hazards and Potential Contributor to Landslides by Landslide Type

Landslide Type	Hazard Potential as Contributor to Landslides			
	Wildfire	**Intense, Short-term Rainfall**	**Prolonged Rainfall**	**Rapid Snowmelt**
Earth Flow	+++	+	+++	+
Debris Flow	+++	+++	+++	+++
Debris Slide	+++	+++	+++	+
Rock Slide	+	+++	+++	+
Rockfall	+	+++	+++	+

+++ Major potential contribution to landslides
++ Medium potential contribution to landslides
+ Minor potential contribution to landslides

Table 3 presents candidate resilience strategies, which are detailed in the following sections, and **Table 4** outlines the stressors and hazards that may be mitigated by these strategies. It is important to note that different types of landslides can be affected by multiple stressors as well as other factors. Thus, designing an appropriate resilience strategy involves more than addressing a single stressor. For instance, dealing with drainage issues on a slope prone to debris slides does not eliminate the risk entirely. Evaluating stressors, slope conditions, and other factors is essential for choosing effective resilience strategies.

Table 3: Applicable Landslide Types for Resilience Strategies

Resilience Strategies	Applicable Landslide Types				
	Earth Flow	**Debris Flow**	**Debris Slide**	**Rock Slide**	**Rock Fall**
Enhanced Drainage	+++	+++	+++	+++	+++
Debris Flow Catchment	+	+++	+++	++	++
Reduction of Driving/ Resistance Force	+++		+++	+++	+++
Subsurface Drainage	+++	+++	+++	+++	+++
Vegetation and Seeding	+++	+++	+	+	+
Bioengineering and Biotechnical Stabilization	+++	+++	+	+	+

Note: Nature-based solutions indicated in green.

+++ Major potential contribution to landslides
++ Medium potential contribution to landslides
+ Minor potential contribution to landslides

Table 4: Stressors and Hazards Mitigated by Resilience Strategies

Resilience Strategies	Wildfire	Intense, Short-term Rainfall	Prolonged Rainfall	Rapid Snowmelt
Enhanced Drainage		+++	+++	+++
Debris Flow Catchment	+++	+++	++	++
Reduction of Driving/ Resistance Force	N/A			
Subsurface Drainage		+++	+++	+++
Vegetation and Seeding	++	+++	++	+
Bioengineering and Biotechnical Stabilization	N/A			

Note: Nature-based solutions indicated in green.

+++ Major potential contribution to reducing hazard impacts

++ Medium potential contribution to reducing hazard impacts

+ Minor potential contribution to reducing hazard impacts

As noted above, identifying the most effective means of mitigating potential impacts from unstable/erodible slopes depends on understanding the factors that contribute to unstable conditions. In some cases, steep slopes can be stabilized by reducing the slope angle, large earthflows can be stabilized by constructing a toe berm to increase the resistance to sliding, rockfall areas can be draped with wire mesh or stabilized with rock bolts to prevent future rockfall, and erodible soil can be stabilized by planting grasses or native plants creating a root mat that helps hold soil in place. KYTC has many decades of experience with such strategies. Considering Kentucky's mountainous terrain in eastern Kentucky and evolving conditions, future challenges may need to be addressed in project designs. It is important to note that the KYTC Geotechnical Guidance Manual, which lays out the investigation and mitigation of landslides and rockfalls, is the basis for Engineered Strategies.[5]

Enhanced Drainage

-- Intense, Short-term Rainfall *-- Prolonged Rainfall, Rapid Runoff*

Rainfall levels and intensity are factors that contribute to slope instability and erosion. Thus, a primary method of resilient landslide mitigation is to provide enhanced drainage and infiltration design. Surface runoff and subsurface groundwater movement can result in soil instability. With sufficient drainage control, these effects can be managed or controlled using engineered solutions.

Engineered systems to collect surface runoff are essential elements of safe highway design. Drainage collection designs that concentrate the erosive capacity of surface water flow by focusing the flow into much smaller drainage areas can increase slope instability or denudation. A more resilient system could incorporate both drainage collection and distribution along a highway. This strategy would reduce the potential for washouts. Long-term performance of these drainage systems depends on periodic maintenance to ensure they are operating as designed.

[5] KYTC. 2005. Geotechnical Guidance Manual. Accessed at https://transportation.ky.gov/StructuralDesign/Interim%20Guidance%20Manual/Geotechnical.pdf, last accessed February 28, 2025.

Debris Flow Catchment

-- Wildfire *-- Intense, Short-term Rainfall* *--Prolonged Rainfall, Rapid Runoff*

When slopes are subjected to focused and intense rainfall, resulting debris flows can become another type of slope instability. In many cases, by virtue of topographic contours, hillslopes themselves can also collect and focus runoff. This phenomenon is one of the primary causative factors in triggering debris flows. Mitigation of debris flows can be achieved by providing sufficient subsurface drainage to prevent failure conditions from developing. However, in some cases, the source for a debris flow is far from the potential impact locations; in such a case, enhancing the drainage design in source areas might be challenging due to cost or access constraints.

Reducing the impacts of debris flows might also involve the construction of debris flow catchment fences across drainage channels to intercept debris flows and stop or slow the flows (**Figure 3**). This strategy has gained more widespread acceptance in recent years as in-the-field experience has occurred. Like drainage systems, maintaining these debris flow mitigation measures is also critical to ensure that they remain effective.

Figure 3: Example of Debris Flow Detention Fencing as Designed (Left) and Holding Back Debris Flow (Right)

Reduction of Driving/Resistance Force

Potential landslides that form by shear failure on a discrete plane or series of planes are usually identified as part of the design process. However, slope cuts and fills that are frequently used in highway construction can activate old dormant slides or slides that had not been identified. Mitigating such slides usually include two types of strategies: either reduce the driving forces causing the failure or increase the resistance forces that govern slide movement. An example of reducing the driving force is to excavate or remove material from the top of a slide mass so that the weight of the slide mass (a driving force) is reduced to arrest movement. An example of increasing the resistance force is to add fill to the base or toe of the slide to increase the weight that resists the forces from above, thus making it harder for the slide to move. Structures such as retaining walls, soldier pile walls, soil nails, rock bolts, tie-backs, and other structural means of ground support may also be applicable mitigation measures for stabilization by increasing resistance for a specific slide. These general concepts are useful in many different types of slides.

Subsurface Drainage

-- Intense, Short-term Rainfall -- Prolonged Rainfall, Rapid Runoff

Reducing pore-water pressures or groundwater levels is another mitigation method related to rainfall and groundwater that can act to reduce landslide driving forces. This is accomplished primarily by providing subsurface drainage (Figure 4). Subsurface drainage can be an effective means of stabilizing both small and large landslide locations. By providing drainage, water levels decrease, thus reducing the driving force and increasing the strength of the slide zone.

Figure 4: Drainage to Stabilize Slope

Vegetation and Seeding

--Wildfire --Intense, Short-term Rainfall --Prolonged Rainfall, Rapid Runoff

One set of strategies to reduce erosion is vegetating and seeding slopes. The roots help to hold soil in place and plants help to slow the flow of runoff. However, vegetation cannot prevent deeper landslides, as the main goal with this strategy is to provide soil stabilization – that is, a shallow portion of the slope. Best practices for vegetating and seeding slopes involve the use of native plants and ground cover.

Runoff Management

Vegetation can also manage runoff when placed at the top of a slope or close to the impervious runoff source, thereby intercepting the runoff before it can make it down the slope. Infiltration trenches, diversion berms, and pervious pavement can also achieve this effect, especially if the trenches/berms direct any excess runoff away from the slope. Another runoff management technique is soil enhancement: organic matter is more absorbent than inert matter, so increasing the organic matter content of the slope's soil can improve its ability to absorb runoff without eroding. Materials such as compost, aged mulch, manure, and sewer sludge can be used for this purpose.

Bioengineering and Biotechnical Stabilization

The strategies described thus far work to promote slope stability by decreasing soil erosion. Another set of strategies, biotechnical stabilization, has a similar goal, but often work by creating forces that counteract or otherwise decrease shear forces. For example, adding a berm at the toe of the slope increases downhill weight, creating a counterforce that resists slope failure. Biotechnical stabilization also generally involves a greater level of labor and construction than bioengineering (the use of plant material, living or dead), as biotechnical stabilization can make use of inert structural components, such as terracing, stones, green walls, and geotextiles.

WILDFIRES

The increasing incidence and magnitude of wildfires, in addition to other anthropogenic factors such as more people living in the wildland-urban interface, have serious consequences for people who live in high fire-risk areas. Drought-induced wildfires can create dangerous “black out” conditions for road users. There are several prevention strategies that be applied or expanded to mitigate the risk of wildfires adjacent to the state highway network. The resilience strategies for this strategy are classified in three categories: defensible space, fire-resistance landscaping, and materials selection.

Defensible Space

KYTC can avoid the ignition of wildfire and prevent damage in the event of a wildfire by maintaining defensible space around its facilities and assets. Defensible space is a buffer that is created between a building or asset and the vegetation surrounding it. This space slows or stops the spread of wildfire and additionally protects the building from radiative heat impacts. For KYTC, defensible space could be applied not only for buildings, but to roadway assets along the right-of-way (signs, guardrails, etc.).

Fire-Resistant Landscaping

KYTC can use fire-resistant landscaping along its right-of-way and outside of its facilities to prevent fire ignition and slow or stop the spread of an existing wildfire. Water conservation is another benefit to using fire-resistant landscaping, as plants that are fire-resistant are typically drought- tolerant natives. Fire-resistant landscaping could be used anywhere in the state but is especially pertinent in the locations defined above. Creating a fire-resistant landscape involves using high-moisture plants that are resistant to ignition and have a low sap content, trees that are less flammable than other species, and rock, mulch, gardens, stone walls, and other landscape features to create fire breaks.

Material Selection

KYTC could harden its facilities to prevent ignition and damage to buildings and assets by using ember- and heat-resistant materials. Some of these changes are straightforward and are already being implemented by many states. For example, in some cases, state DOTs have replaced plastic culverts with metal ones to prevent them from melting in the event of wildfire. Likewise, in fire-prone areas, some DOTs have replaced wooden signposts and guardrail posts with metal posts.

In the case of DOT buildings, many strategies can be taken to reduce the risk of ignition from an ember and/or radiative heat. Several recommendations on how to harden commercial buildings to reduce wildfire risk come from the Insurance Institute for Business and Home Safety (IBHS):

- Use noncombustible materials for all signage.
- Use noncombustible exterior wall cladding such as concrete and brick, ensure the start of siding is at least six inches off the ground.
- Use windows that are dual-paned with tempered glass.
- Use 1/8-inch noncombustible mesh screening over vents.
- Use noncombustible materials for rooves and gutters, regularly clear these of debris.
    - Select noncombustible gutters and downspouts like aluminum
    - Choose Class A fire-rated roof covers based on testing to ASTM E108 or UL 790
- Use noncombustible materials for desks, such as lightweight concrete, tile, metal, and fiber cement.
- Alternatively, use a combustible product that complies with the state building code.

HIGH WINDS

High winds can significantly impact a state's transportation system, both from an asset damage perspective and from an operations perspective.

ASSET DAMAGE

Structures and ancillary assets (such as signs) are designed to withstand a specified wind design speed and often for a materials fatigue category. The Georgia Department of Transportation, for example, has design specifications for lighting poles that require a wind speed design of a 1700 Mean Recurrence Interval (MRI) with a materials[6] Fatigue Category 1 for four regions of the state, including design wind speeds of 120 mph, 130 mph, 140 mph, and 150 mph. One of the engineered strategies that can be used is to modify the design wind speed if it is determined that higher wind speeds are likely to occur during the lifespan of the asset. Replacing signals on wires with mast arms and changing signposts from wood to metal are options. The other primary engineered strategy is to provide a wind barrier for key assets that would protect them from the wind forces that could cause damage. A natural infrastructure strategy might be to use trees to provide such a barrier.

A DOT's buildings could also be exposed to damage from high winds. One of the strategies used for buildings is to wind-proof as much of the structure as possible, including the use of materials and connections that can withstand high wind speeds.

OPERATIONS

High wind speeds can also affect DOT operations and users of the transportation system. For example, there are many locations in the U.S., particularly on bridges and in mountainous areas, where high wind advisories are posted especially for trucks. In some cases, truck movement is limited in such circumstances.

For the DOT, high winds can (1) lead to a loss of power to traffic signals and communication systems, (2) create dangerous situations for DOT personnel who respond to system disruptions, (3) result in large amounts of debris scattered along a highway, and (4) cause trees to fall along the right-of-way. Many states have adopted a range of strategies to avoid and minimize operational disruptions from high winds.

Tree Clearance from Right-of-Way

One of the ways state DOTs try to protect traffic operations from storm-related obstructions is to remove potential obstacles before they can block a road. One of the most significant strategies is to cut back trees in the right-of-way in locations where the trees are very close to the road surface. By so doing, the DOT is minimizing the risk of trees falling on the travel way or trees falling on power or communication lines.

Expedited Debris Clearance Policies

DOTs have realized that removing debris from the road surface as fast as possible is one of the most effective strategies for road recovery (assuming there is no serious damage that has to be fixed). Although some DOTs rely on their own personnel and equipment for doing this, many have contracted out debris removal/management efforts to private contractors (as does KYTC). By so doing, a DOT is able to augment its response to a disaster by calling upon additional resources that are not part of the daily system operations (this assumes of course that contractors are available and willing to provide such temporary services).

[6] Georgia DOT. 2021. Construction specifications. Accessed March 11, 2025 at https://www.dot.ga.gov/PartnerSmart/Business/Source/specs/2021StandardSpecifications.pdf.

Agreements with Power Utility Companies

With respect to power loss, many state DOTs have long-standing working relationships with utility companies to respond to power outages. In large-scale disasters, this might include utility companies from outside the state. For traffic signals, the recovery process usually includes both participation of the DOT and the utility company to assure that the signals revert to the pre-disaster operational configuration.

Traveler Information

Studies have shown that one of the most important components of a successful operations recovery effort is conveying information to the traveling public on (1) what roads are closed or have limited capacity, (2) what detours or alternate routes are available, and for through traffic (3) where emergency facilities or housing accommodations are available. This can be done via social media, radio, the 511-information network, on-road variable message signs, and other intelligent transportation system (ITS) media. In addition, a more physical means of conveying non-used of damaged roads is road closures via police presence or by blocking ramps (some state DOTs have constructed gates are ramp exits and entrances that can be used during emergencies to block traffic from using the road).

WINTER STORMS

Extreme winter storms feature snow and ice that create further hazards for road users. Strategies that have been used by state DOTs include the following:

Prepositioning of Snowplow Equipment to Provide Rapid Response to Deteriorating Conditions

In anticipation of an on-coming storm, most states that are familiar with winter storm disruptions pre-position their personnel and equipment to locations that are expected to be hardest hit. This presupposes that the predicted storm track will in fact be close to what will likely happen. By prepositioning personnel and equipment, a DOT is minimizing the amount of time it will take to respond to snow and icy road conditions. To have the most up-to-date information on which to employ its resources, some state DOTs (e.g., Utah DOT) have hired their own meteorologists to work with their maintenance and operations staff to implement the most effective strategy. A major challenge in pre-positioning personnel is the need for housing/lodging.

Application of Anti-Icing Material (Such as Brine)

Like the prepositioning of personnel and equipment, applying anti-icing materials before the storm becomes too strong is a way of getting ahead of the problems that such a storm could cause to a road network and to highly vulnerable locations (such as steep inclines/declines). This strategy again depends on knowing where the worst impacts of the storm are likely to occur on the road network.

Use Real-time Monitoring (Often via Interactive Communications and GPS Information with Snowplows) of Changing Weather Conditions

A snow and ice removal strategy needs to be flexible and adaptive to rapidly changing conditions. Thus, it is important that a DOT has the most up-to-date information on road conditions. This has been done be some DOTs (e.g., MnDOT) by linking image and speed monitoring from their snowplows to a central dispatch location. Others (e.g., Florida DOT) are applying real time monitoring of water elevations at key bridge locations. This strategy has also been discussed as a possible role for connected vehicle technology where the vehicles using the road network become probes that provide information on road conditions.

Use of Snow Fences at Locations that Often Experience Snow Drifting onto the Road Surface and the Use of "Living Snow Fences"

A common strategy for reducing snow drifts on road surfaces is to use snow fences as a way of blocking the accumulation of snow on the road surface. Some DOTs (e.g., MnDOT) have been using "living" snow fences, that is, the use of trees and other vegetation, to serve the same purpose.

Application of Road Weather Information System (RWIS) Technologies to Warn Drivers of Hazardous Road Conditions

The Federal Highway Administration (FHWA) and many state DOTs have deployed monitoring and communications technologies at key locations where hazardous environmental conditions might occur (e.g., high wind locations). RWIS technologies conduct real-time monitoring of the environmental conditions and then display on message signs appropriate levels of warning to road users.

MEMO

TO: Tracy Nowaczyk (KYTC)

FROM: Elizabeth Farc (WSP), Chris Dorney (WSP), and Mike Meyer (independent consultant)

SUBJECT: Task 1.5, Recommendations for Identifying Resilience-Oriented Projects

DATE: May 23, 2025

Natural and human-made hazards present potentially significant threats to Kentucky's transportation system, leading to substantial challenges for the Kentucky Transportation Cabinet (KYTC). Not only can such threats cause important assets to fail, but they can also accelerate the deterioration of infrastructure, raising maintenance costs and overall expenses. Aging infrastructure based on older design standards is particularly vulnerable. Additional costs arise from economic losses due to traffic diversions and delays. Perhaps most importantly, these hazards also represent safety risks to roadway users. There are indications that Kentucky is seeing an upward trend in these hazards and that this trend will continue for the foreseeable future.

To address such challenges, new resilience-oriented projects and the addition of resilience enhancements to already planned projects are needed. This memorandum begins by reviewing how resilience is currently considered in project programming and budgeting at KYTC. Given this context, it then offers specific recommendations on how KYTC can enhance resilience project identification and budgeting.

RESILIENCE AND KYTC'S CURRENT PROJECT PROGRAMMING AND BUDGETING PROCESSES

Every two years, KYTC develops a six-year highway investment plan (the Enacted Highway Plan), in coordination with local stakeholders and the General Assembly. The first two years of the Enacted Highway Plan constitute committed projects and the remaining four years include recommended projects to be considered for inclusion in the next Plan. **Figure 1** shows the project selection and prioritization processes used in developing the Enacted Highway Plan.

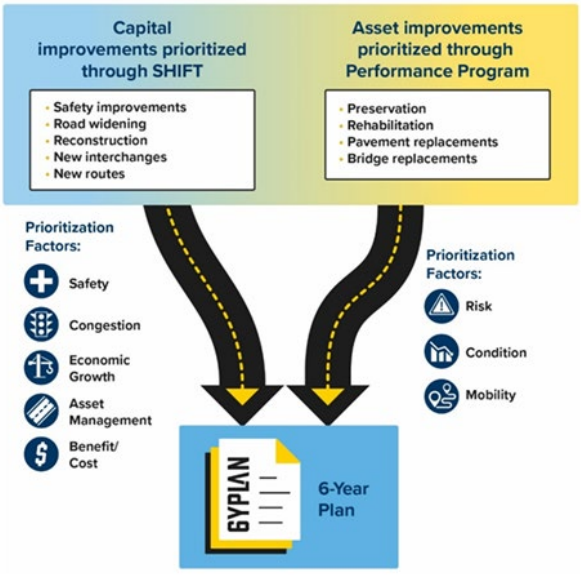


Figure 1: Project Selection and Prioritization Processes used in Developing the Enacted Highway Plan

Source: KYTC. 2022. Transportation Asset Management Plan. *KYTC_2022 TAMP BIL Submittal.pdf*

The focus of this memo is on: (1) asset management and performance projects (featuring state of good repair-oriented preservation, rehabilitation, and replacement projects drawn largely from the Performance Program), (2) capacity improvement projects (the focus of the SHIFT process), and (3) operations and maintenance (O&M) projects that are managed through Central Office (these are not included as individual projects in the Enacted Highway Plan but, instead, are included within the ZVARIOUS set aside funds). Resilience-enhancing projects and/or project elements can be included in all these project categories. The following sections describe how resilience is currently considered within each of these focus areas.

ASSET MANAGEMENT AND PERFORMANCE PROJECTS

Asset management projects mainly address asset condition needs, in many cases directly linked to weather and hazards. The Enacted Highway Plan highlights that KYTC's Transportation Asset Management (TAM) framework (1) "reduces risks from unplanned events such as flooding" and (2) "enhances system resilience." The 2022 Transportation Asset Management Plan (TAMP), a 10-year plan for pavement and bridge investments, further details how resilience is integrated into asset prioritization before inclusion in the Enacted Highway Plan. The TAMP emphasizes system resilience as a key risk for KYTC. For example, the TAMP states that pavement deteriorates over time from traffic and weather, while bridges and culverts are vulnerable to scour during periodic floods. Risk (including weather-related risks) is one of three major factors in asset management prioritization, along with condition and mobility. This section briefly explains how the TAMP identifies and prioritizes resilience projects, starting with the TAMP risk register, and then discusses project identification and prioritization for pavements and bridges.

RISK REGISTER

KYTC created a risk register to identify potential future risks in delivering its program. While not used for project identification and prioritization, this process provides important context for KYTC's risk-based approach to asset management and program delivery. This background is crucial for project identification and prioritization under the Performance Program, as noted in the TAMP.

The risk register is designed to support the identification of new risks as they become apparent over time. An interactive process involving subject matter experts and others identified a set of risks related to KYTC's management of pavement and bridge performance and condition. These risks pertain to finance, climate, extreme weather, technology, workforce development, construction materials, and organizational processes.

The risk register identified a list of potential risks facing KYTC. The following risks relate directly to resilience:

- Inadequately trained and experienced bridge inspection staff leading to an inability to promptly inspect bridges after extreme weather events.
- Inadequately trained and experienced staff to identify scour vulnerabilities and address scour countermeasure repairs leading to accelerated bridge degradation and failures.
- Increasing precipitation leading to increased flooding and scour, possibly more safety incidents due to low skid-resistance, and accelerated bridge deterioration due to increased use of de-icing chemicals.
- Experience with major storm events leading to increased damage to KYTC assets and increasing threats of flooding resulting in a greater need for debris removal.
- Possible increases in extreme temperature events leading to accelerated pavement deterioration, construction delays, and possible increased concrete pavement deterioration.

As described in the TAMP, the Risk Register is reviewed at least once every six months, or if there is a significant event or risk trigger (such as major changes in funding, unplanned initiatives, significant natural disasters, or changes in leadership).

PAVEMENTS

Life cycle costing in pavement asset management involves factors like weather impact, travel demands, and rising costs. KYTC identified these environmental threats for Kentucky's highways:

- Temperature extremes (high and low)
- Higher average precipitation levels
- More extreme rainfall events
- Increasing numbers of flooding events

The TAMP notes that KYTC is either adopting or is considering a range of strategies for protecting pavements against such threats, including: (1) periodically evaluating potential issues such as the suitability of asphalt binder grades given temperature trends; (2) conducting research on optimizing asphalt mix designs; (3) improving the quality of pavement construction through enhanced inspection, acceptance, and project delivery; and (4) increasing efforts to seal cracks and joints in existing pavements and inventorying drainage assets in ways that areas of concern can feed into project prioritization.

KYTC uses a process to score pavement sections for priority treatment and includes rating pavement condition, with emphasis on higher functionally classified roads. This scoring is based on: (1) an overall Pavement Distress Index (PDI), (2) an average Remaining Service Interval (RSI), (3) a Pavement Sustainability Ratio (PSR), and (4) the International Roughness Index (IRI). Resilience is not considered as an explicit factor in this process. The TAMP does note, however, that KYTC,

> "Considers a balanced priority between preservation and major rehabilitation/reconstruction actions that not only ensures that 'Good' pavements continue to provide a good level of-service for the road users, but pavement sections that are more vulnerable to extreme weather events receive a fair allocation of funding to address imminent risks. Based on routine vulnerability assessments, if a certain portion of the KYTC pavement network is found to be more vulnerable to extreme weather events, the pavement deterioration models and treatment strategies will be recalibrated to help improve the network's overall resilience."

BRIDGES

As part of the agency's bridge asset management, KYTC utilizes a bridge management system (BMS) called AASHTOWare Bridge Management (BrM), which relies on National Bridge Inventory (NBI) metrics. Bridge condition performance metrics used to identify and prioritize projects include those required by the Federal Highway Administration (FHWA) such as the percentage of deck area for bridges with a 'poor' condition rating. KYTC has adopted a desired state of good repair target of 97% of the federal-aid system bridge deck area being in 'good' or 'fair' condition. KYTC's TAMP also notes that the "BMS considers resilience characteristics of a bridge affecting road user safety and mobility, including advanced deterioration, clearances, and scour. Bridges having significant risk of service disruption receive greater priority for improvements or replacement." This is primarily accomplished by using the functional classification of the roadway to indicate potential level of disruption and by use of a Bridge Prioritization Index (BPI).

According to the TAMP, the BPI is a "supplement to the BMS to ensure that all relevant goals and objectives, particularly safety and mobility, are appropriately considered in programming decisions." The BPI considers safety, condition, mobility, and risk concerns relating to each bridge. Specific indicators that are used in the index include:

- Bridge condition
- Age
- Scour criticality
- Fracture criticality
- Existence of fatigue-prone details
- Vertical and horizontal clearance
- Frequency of inspection
- Bridge load posting
- Traffic and truck volume
- Detour length
- Route designation (National Highway System, emergency route, school bus route)

Note that the BPI does not include other NBI factors that might be of importance in terms of potential bridge damage, such as a lack of capacity to pass water under the bridge (i.e., the waterway adequacy rating).

Separate from the BPI, a flooding vulnerability tool was developed by the Kentucky Transportation Center (KTC). The tool uses NBI data to develop flood and scour risk indicators. Three factors are considered to identify relative risks among different structures:

- "Structural Condition—Evaluates the overall structural integrity based on NBI data.
- Geomorphic Sensitivity—Evaluates channel condition, scour potential, and observed scour.
- Criticality—Evaluates how integral an asset is to the transportation network."[1]

These factors are then used to determine an overall vulnerability value for each bridge location ranging from one to three, with three representing a bridge with the highest vulnerability to bridge scour. **Figure 3** shows the results of an analysis to identify hot spots for structures with high sensitivity to scour and flooding (hot spots indicate an area where several sensitive structures are close together). KYTC is currently developing a method to incorporate this work into project decision-making.

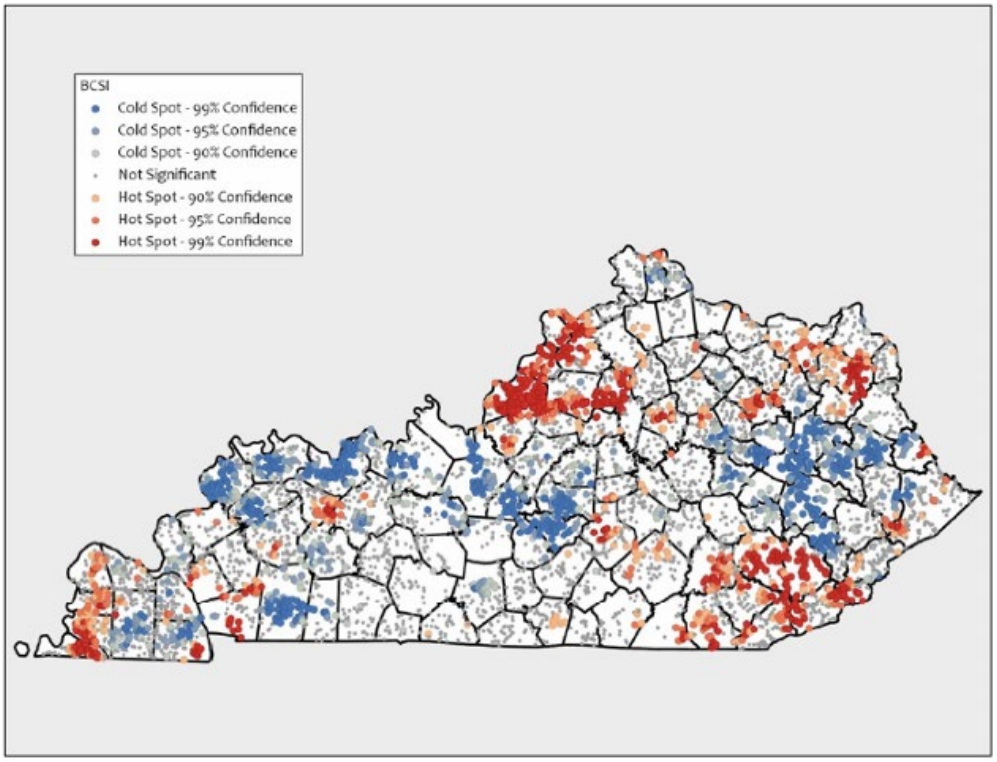


Figure 2: Bridge Scour Criticality Index Hot Spots (Blandford, et al. 2019)

CAPACITY IMPROVEMENT PROJECTS

Capacity improvement projects are prioritized for inclusion in the Highway Plan using SHIFT, a data-driven, objective approach to compare proposed capital improvement projects and prioritize limited transportation funds. SHIFT was developed to reduce overprogramming and to provide a clear understanding of future project construction. The formula-based approach applies to all transportation funding that is not prioritized by other means such as asset management, local government projects, and dedicated federal projects. It is important to understand how SHIFT is used to place in context a later discussion on how KYTC can enhance its consideration of resilience factors when establishing investment priorities.

[1] Blandford, B., et al. 2019. Kentucky Pilot Project on Asset Management, Extreme Weather, and Proxy Indicators: Final Report, Kentucky Transportation Center, Lexington KY. Accessed at https://www.fhwa.dot.gov/asset/pilot/ky.pdf.

Resilience is considered at multiple points in the capital improvement project development process. First, it may play a role in project identification, but this is not formalized. In the initial project scoring within SHIFT, resilience is considered by measuring (1) betweenness centrality and (2) detour importance. Betweenness centrality measures a highway segment's importance in providing connectivity and accessibility in the region (primarily measured by functional class of a road, which reflects its importance to overall network functionality), while detour importance quantifies its significance in serving as a detour of other roadways in the region when they are closed. With these measures, KYTC links resilience to the importance of a road segment in both its role for supporting economic and social interactions in a region and its role in supporting the functioning of the road network when disruptions occur. Note that there is no direct consideration of hazards or their likelihoods in the SHIFT process.

Also, with respect to scoring, it's worth noting that other SHIFT prioritization factors beyond the explicitly defined resilience factor could be positively impacted from project resilience enhancements. Examples of these other SHIFT factors that could be related to resilience include safety, congestion reduction, and benefit-cost analysis (BCA). That said, it does not appear that the SHIFT process is currently set up to capture the benefits of resilience enhancements to these factors. The recommendations later in the memorandum will provide some suggestions on how the multi-parameter SHIFT scoring could provide a pathway to do so.

OPERATIONS AND MAINTENANCE ACTIVITIES/PROJECTS

O&M activities are often on the "front line" of resilience strategies. O&M efforts play a critical role in preventative maintenance activities like keeping water flows moving through drainage systems (e.g., removing debris from culverts and channels) and are also critical in responding effectively to unexpected disruptions after extreme weather events (e.g. cleaning up a rockslide). In addition to these O&M activities, the KYTC Division of Maintenance also oversees small capital projects that are aimed at fixing a current problem or to put in place the needed structures to avoid future problems. KYTC maintains a list of requested maintenance projects submitted by District staff and selects projects for funding based on seasonality, geographic region, and events. Increasingly, KYTC Central Office is receiving proposals for larger maintenance projects that are related to resilience needs (e.g. significant tree trimming or rockfall projects). While resilience is often a factor in these projects, there is no formal scoring or prioritization process for these projects that considers resilience. It is likely that some of these capital projects could be approached from the perspective of enhancing the resilience of a particular roadway or roadway segment, and this is discussed further in the recommendations.

RECOMMENDATIONS TO ENHANCE RESILIENCE IN PROJECT PROGRAMMING AND BUDGETING

Recommendations on enhancing resilience considerations in KYTC project programming and budgeting are organized by the three focus areas presented in the previous section: (1) asset management and performance projects, (2) capacity improvement projects, and (3) O&M projects. Where appropriate, the recommendations are also organized by those that are (1) applicable to projects already in the Enacted Highway Plan pipeline and (2) those that have yet to enter the pipeline. This latter category is intended to help KYTC better identify new resilience-focused projects or promote resilience enhancements to projects motivated by other needs.

ASSET MANAGEMENT AND PERFORMANCE PROJECTS

PROJECTS IN THE CURRENT ENACTED HIGHWAY PLAN

Relate Vulnerability Assessment Outputs to Planned Projects: KYTC might consider undertaking a geospatial analysis that overlays proposed projects coming from the asset management process with the outputs of KTC's vulnerability assessments. At this point, the asset vulnerability scores in the vulnerability assessments have been developed using FHWA's Vulnerability Assessment Scoring Tool (VAST). A risk monetization tool is being developed by KTC to support future vulnerability assessments and enhance the actionability of the output information. The screening process for determining which projects to prioritize for resilience strategies involves using a risk monetization tool alongside a resilience benefit/cost analysis. The quantification of risk reduction in monetary terms would offer a clear understanding of the resilience benefits derived from each project and could be added as a factor in their prioritization.

Understanding that work on risk monetization is still ongoing, the currently available data from the VAST analysis does provide information that can be used to identify where vulnerabilities exist in Kentucky's road network. Performing an overlay of VAST outputs with planned projects would identify the vulnerabilities of the current assets in each project's vicinity to various natural hazards. The vulnerability scores of individual assets within each planned project can be summarized across the project extent to enable a relative ranking of planned projects by their potential ability to address indicated vulnerabilities. Appendix A provides an example of this process from the work informing the Minnesota Department of Transportation's (MnDOT) Resilience Improvement Plan using similar indicators-based vulnerability scores to what KTC developed.

Provided the results of the overlay analysis, project managers could be asked to examine each of their projects for opportunities to enhance resilience and update their Data Needs Analysis Studies (DNAs) and/or other project planning documents accordingly to incorporate resilience features. The *Task 1.4 Potential Resilience Strategies* memorandum from this project could be shared with them as examples of the types of strategies that might be added to the project scope to protect against future damage and disruption. This activity might be most applicable to the recommended projects in the Plan (i.e., those starting in plan years three through six), as committed projects will have less ability to incorporate new resilience considerations.

To further support such assessments and resilience decision-making in general, KYTC might consider providing more detailed guidance and tools for how to consider resilience in the project development process. This facility-level assessment guidance could touch on established processes for doing these analyses (e.g., FHWA's Adaptation Decision-making Assessment Process [ADAP][2]), sensitivity testing of designs against different potential future scenarios, common design strategies, economic analysis for resilience investments, and

[2] https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/adap/

decision-making approaches. Tools could also be developed/implemented that facilitate sharing of hazard data with project managers (e.g., through web-based mapping) and that support resilience BCA (e.g., FHWA's Climate Risk Assessment [CRA] Tool; see below for more information on resilience BCAs).

IDENTIFICATION OF PROJECTS FOR FUTURE HIGHWAY PLANS

Leverage Vulnerability Analysis Outputs when Scoping Asset Management Projects: Like the discussion for existing planned projects above, KYTC could implement a system whereby new projects surfacing from the asset management process will be assessed against hazard data to identify opportunities to consider resilience enhancements. This could occur as part of the Continuous Highway Analysis Framework (CHAF) project requests that develop initial candidate project scopes and be integrated into the DNAs for projects that progress to this stage. For the CHAF, changes may include:

- Displaying hazard data in the Map feature
- Including bridge exposure and risk data in the View Bridge Details feature
- Guidance to explicitly include a discussion of resilience factors in the Purpose and Need sections (as appropriate)
- Guidance to include resilience enhancements (as appropriate) in the development of the initial cost estimate
    - Define and include different, more specific resilience enhancement options for the Improvement Assumptions drop-down
    - Allow the user to select multiple items in the Improvement Assumption dropdown (primary, secondary, etc.). This would allow a project primarily being done for some reason other than resilience (e.g., Arterial to Partial Control) to also be recorded as having some form of resilience enhancement(s) as well.
    - Include a line item on resilience enhancements so that the incremental costs of these enhancements can be tracked (for resilience-focused projects, this would be the same as the full cost of the project)
- Under Project Characteristics, add a question on what hazards the project would address. Like the other questions, provide buttons and allow the user to select multiple hazards. This might fit under the question, "Which of the following might this project support?" with a subheading saying "Resilience to:" and then have the buttons follow.

For the DNAs, the template could be updated to include:

- A statement on the compiled VAST vulnerability score for this project location (if a cross-asset score is developed similar to MnDOT) or the VAST vulnerability scores of individual assets in the project limits.
- For bridges, it might be beneficial to include the bridge scour score.
- The DNA includes a section called System Linkage, which allows the author to indicate which other system goals the project will likely benefit over and above the primary project purpose (e.g., a capacity project would likely provide safety benefits). A "resilience" system category could be included as an input.
- A new resilience element in Section II on Project Purpose and Need along with a statement to consider, where appropriate, resilience implications in the descriptions for the other elements (e.g., safety, etc.). The new resilience element could require discussion about past hazards experienced in the area and their impact on the public.

- New elements within Section III, the Preliminary Environmental Overview, documenting current and future hazards that might impact the project area (e.g., floodplains, slide-prone slopes, etc.). This section could leverage data created in the vulnerability assessments.
- A discussion on how the proposed project will address the resilience needs identified in Sections II and III. This could require evidence that at-risk projects utilize a facility-level assessment like ADAP to determine if/how to address resilience needs.

Re-examine Resilience Considerations as a Factor in Asset Management Prioritization Processes: There are several areas within the asset management project prioritization processes where resilience considerations could be enhanced.

- For pavements, KYTC could consider how future forecasted conditions may affect RSI and PSR under different future scenarios and incorporate these into the pavement project prioritization process
- For bridges, the BPI could be updated to consider the waterway adequacy rating in the NBI. The waterway adequacy rating records a qualitative evaluation of overtopping frequency and attendant traffic impacts. Over time, this measure could be improved to consider hydraulic modeling outputs of flood frequency for current and future conditions. Flood frequency information for current conditions is likely already available for many bridges through Federal Emergency Management Agency (FEMA) hydraulic modeling. What is needed is a systematic effort to query this information and record it in KYTC databases.

More fundamentally, the following broader concepts could be considered as longer-term goals in the evolution of the asset management program:

- Consider transitioning the entire asset management system towards a risk monetization approach, moving away from qualitative risk matrices and indicator-based indices. As mentioned above, KTC is currently developing tools that may help facilitate this transition.
- Given the deep irreducible uncertainty in knowing future environmental considerations, a scenarios-based approach to decision-making is recommended for all elements of the TAMP (including performance gap assessment, risk register, life-cycle plan with life-cycle costing, and investment/financial plan). For example, when developing the financial plan, consider different packages of investment options tailored to varying future conditions. Stress test these investments under various potential futures and select projects that offer the most benefits regardless of how future conditions transpire. This would represent a substantial shift in asset management practices, but one that better reflects the uncertainty of future conditions and makes optimal decisions given that uncertainty.
- Consider acute hazards as well as chronic ones in the asset management program. Asset management and the software that supports it are often focused on deterioration curves and asset degradation over the long term due to chronic stressors that are assumed stationary (i.e., not to change over time). While some hazards are chronic, few if any are stationary and many more (including many of the most damaging ones) are acute and come during episodic extreme events (e.g., a flood that damages a bridge, pavement blow-ups during a period of extreme heat). Much of current asset management practice has often ignored these acute hazards when, in fact, they are a critical part of future system disruptions and represent large costs to agencies.
- Consider gaps in the current asset management software which may impede implementation of these recommendations. Many of the off-the-shelf software programs used in support of analyzing future asset conditions and performance do not support non-stationary chronic and acute stressors and

scenarios-based assessments. Should KYTC seek to advance its resilience strategy, it is essential to include a thorough evaluation of software tools in this progression. This may require the need to custom-build new tools that support more sophisticated analyses, possibly by pooling resources with other DOTs through the American Association of State Highway and Transportation Officials (AASHTO), working with the Pew Charitable Trust on their efforts in this space, etc.

Implement a Program to Conduct Facility-Level Resilience Assessments for Highly Vulnerable Assets: Many KYTC assets are vulnerable to natural hazards, and this number is projected to rise as conditions change in the future. The need for resilience-focused projects is great enough that it warrants developing a program for undertaking facility-level assessments at high-risk assets. Facility-level assessments are conceptual engineering scoping studies (using processes like ADAP) that help determine the most appropriate resilience investment at each problematic location. Thus, the primary purpose of this program would be to create a pipeline of resilience-focused projects that could be proposed for the Highway Plan and take advantage of federal resilience programs like PROTECT. Even if this funding becomes more limited soon, having done the assessment may prove valuable should the existing asset be damaged in an extreme weather event and need repairs. In that case, a betterment alternative (entailing improvements to an asset's resilience relative to its original design) may be available "off the shelf", expediting the recovery process in a more resilient way and avoiding the rush to replace-in-kind in order to restore functionality as quickly as possible.

As a facility-level assessment program would likely take several years to work through the backlog of resilience needs, a prioritization process would be required to determine which assets to study first. Ideal initial candidates are known problem locations from past events such as the repeat-damaged assets discussed in the TAMP. These are the most likely assets to be damaged again by extreme weather events in the near term and benefit from betterments. Highly vulnerable assets from the VAST vulnerability assessment are also likely high priority.

A BCA is a valuable tool for any facility-level assessment to (1) determine the cost-effectiveness of doing any resilience enhancement, (2) choose the most cost-effective adaptation strategy for a project, and (3) ascertain the right level of protection to provide. Resilience BCAs differ from conventional transportation BCAs, which typically illustrate the value of a project in terms of economic development or enhancing safety. The primary reasons for the differences are the need to consider the probability of hazards occurring and understand the impacts/damage from different hazards and different hazard magnitudes.

In a resilience BCA, the benefits are defined as the costs avoided from putting the resilience investment in place (relative to taking no action or, for a new asset, doing a standard design). The costs avoided could include damage/repair costs, user costs, and the broader socioeconomic impacts from a disruption in transportation service. The costs in a resilience BCA are defined as the incremental up-front and ongoing costs to add resilience enhancements (typically, resilience enhancements increase the up-front cost of a project relative to a standard design). A resilience BCA compares the benefits to the costs and produces outputs in the form of benefit-cost ratios (BCRs, benefits / costs), net present values (NPVs, benefits – costs), and/or total lifecycle costs (up-front and ongoing maintenance costs of each alternative + expected damage/repair, user, and socioeconomic costs).

Two primary techniques exist for doing resilience BCAs: Monte Carlo analysis and the area-under-the-curve method.[3] Both techniques result in the same conclusion although Monte Carlo analysis has some added advantages in terms of reporting (i.e., the capability of creating confidence intervals and exploration of individual simulations). Both approaches can consider changing future conditions (or not). FHWA has

[3] More information about each method can be found in a case study FHWA performed comparing the techniques on the Transportation Engineering Approaches to Climate Resilience (TEACR) Project (https://rosap.ntl.bts.gov/view/dot/67094).

developed the Microsoft Excel-based CRA Tool (as of this writing, yet to be released) to help transportation agencies perform resilience BCAs and it is worth considering for use in facility-level assessments and other applications like Emergency Relief Program betterments. For computational efficiency in Excel, the CRA Tool uses the area-under-the-curve method.

Whatever tool/technique is used for performing a resilience BCA, the following best practices are offered for consideration:

- **Consider all the hazards that might impact the asset and their interactions:** Most transportation assets are exposed to multiple hazards. While it is possible to assess each of them in isolation in a resilience BCA, a best practice is to consider their impacts jointly. This enables the consideration of important positive feedback loops that might hasten damage.
- **Consider multiple future scenarios:** If changing future conditions are to be considered as part of the analysis, evaluate multiple scenarios of hazard change. Evaluating multiple scenarios is a way of dealing with the uncertainty in future conditions. It is recommended that at least three scenarios be defined that span the realm of possible future conditions (e.g., a higher, medium, and lower change scenario). To facilitate comparison of results across projects (see below), the scenarios should be consistently defined for all facility-level assessments at KYTC. Perform sensitivity testing of the adaptation strategies under each scenario, generating separate economic metrics for each (i.e., BCRs, NPVs, total lifecycle costs, etc.) then look for the alternative that performs best (or entails least regrets) across the scenarios.
- **Set analysis period to anticipated lifespan of the asset:** Making the period of analysis equal to the anticipated lifespan of the asset will ensure that all the benefits of the resilience investment are fully captured. Sometimes, however, when considering changing future conditions, this is not possible as projections of those conditions don't extend out that far (many don't extend beyond 2099). In these cases, it's prudent to end the analysis at the end of the century.
- **Track changing conditions over time:** If changing future conditions are to be assessed, resilience BCA techniques typically interpolate hazard probabilities between the projection years provided. Often, for simplicity, linear interpolation is used, however, it's important to consider that the projected changes are often not linear. In many cases, the changes can be exponential or even go up and down over time. To capture this complexity (even if using linear interpolation), obtain projections of hazard data at minimum every 20 to 30 years and interpolate within these (narrower) bands as opposed to interpolating between today's conditions and those at the end of the asset's lifespan.
- **Provide a wide range of event magnitudes:** When performing a resilience BCA, it is important to consider all possible event magnitudes that could cause impacts to the asset (e.g., the 10, 11, 12, 13-year, etc. events) up to an event magnitude that is so unlikely it's impacts on the analysis are negligible (typically, the 500-year or 1,000 year event). Considering the full range of magnitudes ensures that the benefits are fully captured for all different types of storm events, not only a subset. As obtaining event probabilities for so many event magnitudes is impractical, resilience BCAs typically obtain projections for a few magnitudes that span the uncertainty space then use interpolation to fill out a probability distribution. To interpolate the distribution more accurately, use a minimum of five return periods spaced strategically throughout the range (e.g., 10-year, 25-year, 100-year, 250-year, and 500-year) as inputs.
- **Consider the impacts from a wide range of event magnitudes:** It is important to consider the different types of impacts that can occur from hazard events of different magnitudes. This is typically accomplished through the development of stressor-damage functions that relate event magnitudes to

expected physical damage to the asset and other impacts (e.g., detour costs due to road closure, etc.). Stressor-damage functions can take many forms, but the most universal one relates hazard magnitudes on one axis to expected costs on the other. Ideally, the assumptions on physical damage underlying the functions are based on empirical study and other engineering calculations but professional engineering judgment can be used in the absence of such information.[4]

- **Include user costs and broader socioeconomic impacts:** It is possible to run a resilience BCA and report the outputs strictly in terms of the cost-effectiveness to KYTC (i.e., cost effectiveness of lowering damage/repair costs from the resilience enhancement) without any consideration of the benefits to system users or broader socioeconomic impacts. While this is an important consideration, it is best practice to also consider the costs to the users of the facility and broader economy from impacts. User costs may consider things like the incremental cost to detour around an impacted roadway (considering added fuel costs, time delays, etc.) and any safety threats presented by the hazards. Socioeconomic impacts might entail lost business activity because of diminished access, follow-on tax revenue impacts, reduced accessibility for first responders, etc. Ideally, two sets of economic outputs (BCRs, NPVs, total lifecycle costs, etc.) would be created and used in decision-making: (1) agency-only values and (2) values with user and broader socioeconomic costs factored in.
- **Perform sensitivity tests:** There are often a lot of uncertainties when performing resilience BCAs. One way to deal with these is to perform sensitivity tests of the results by systematically tweaking some of the uncertain inputs. This is usually easy to do once the analysis has been set up. Because resilience BCAs are often very sensitive to the stressor-damage functions used, if there is substantial uncertainty in the function, consider performing sensitivity analyses using different functions. Discounting (accounting for the time value of money) is another consideration in BCAs and an area where there can be uncertainty on what rate to choose: sensitivity testing the results under different discount rates can provide more confidence in a decision.
- **Consider using NPV or total lifecycle costs instead of BCRs:** While BCRs are intuitive for many, as a value over one can indicate cost-effectiveness, they can be misleading. Simple BCRs do not necessarily account for incremental costs and benefits compared to other alternatives. To avoid confusion, it is often more straightforward to use NPVs or total lifecycle costs.
- **Integrate into larger project BCAs:** Resilience BCAs can be thought of as being one specialized part of a larger project BCA focused on understanding the value of the project of the whole. The resilience BCA metrics (BCRs, NPVs, total lifecycle costs) can be looked at in isolation to understand the effectiveness of different resilience investments. However, it can also be instructive to integrate the resilience BCA results into the broader, more traditional BCA analysis. This can be accomplished either by bringing other non-resilience benefits into the resilience BCA or completing the resilience BCA and incorporating the resilience benefits into the broader BCA.

Implement a Program to Prioritize Resilience-Focused Projects: As weather-related impacts occur and facility-level assessments are conducted for more at-risk assets, the backlog of resilience-focused projects can be expected to increase. Consequently, there will be an increasing need to prioritize which resilience-focused projects are worthy of receiving the limited funding available in any given year. As previously noted, the TAMP financial plan offers an opportunity to explore this for asset management-oriented projects. Different packages of adaptation options could be assessed under different hazard scenarios in the plan and the optimal package of projects chosen (i.e., the package of projects that delivers the most resilience benefits for the

[4] Note: The authors are supporting AASHTO on the development of a document that summarizes the state of the literature on stressor-damage functions for transportation assets. This document is expected to be released to DOTs within the next year.

lowest cost across the future scenarios). If each proposed project entails a BCA done with consistent scenarios/assumptions, the BCA outputs can be used in the financial plan for this purpose.

CAPACITY IMPROVEMENT PROJECTS

PROJECTS IN THE CURRENT ENACTED HIGHWAY PLAN

Relate Vulnerability Assessment Outputs to Planned Projects: Similar to the previous discussion, KYTC could establish a system where recommended capacity improvement projects—specifically those scheduled for years three through six of the Enacted Highway Plan—are evaluated for potential resilience enhancements. Essentially, the recommendations made previously for the "Projects in the Current Enacted Highway Plan" would apply here as well, thus repeating them is unnecessary.

IDENTIFICATION OF PROJECTS FOR FUTURE HIGHWAY PLANS

***Leverage Vulnerability Analysis Outputs when Scoping Capacity Improvement Projects*:** As with the new asset management project recommendations mentioned above, consider requiring all CHAF entries, DNAs, and initial planning studies for new projects (including corridor studies) to have resilience elements. Feature the use of facility-level resilience assessments using processes like ADAP in these assessments.

Re-examine Resilience Considerations as a Factor in the Capacity Improvement Project Prioritization Process: The consideration of resilience benefits in the current KYTC capacity improvement project prioritization process (SHIFT) is primarily addressed by considering the importance of the asset in the functioning of the network. While this is a key consideration in resilience, there are opportunities to enhance the scoring process to better favor resilience-enhancement projects:

- Within the resilience factor within SHIFT, consider adding metrics that ascertain the probability of the new project being damaged by natural hazards (or travel being impeded) under current and future conditions and, if so, how long the travel disruptions might last. The work with KTC on risk monetization is a step in this direction.
- Incorporate resilience benefits and costs directly into the BCA element of SHIFT. As noted above, resilience BCAs are distinct from traditional transportation BCAs in many ways, however, their results can be integrated. In conjunction with encouraging project managers to consider resilience enhancements to their projects, consider performing resilience BCAs for all capacity improvement projects that incorporate resilience-enhancing features. Then, take the incremental resilience costs and benefits and incorporate them into the SHIFT BCA.
- Re-configure the SHIFT process to allow a resilience-enhancing project to take credit in multiple SHIFT consideration areas. For example, a roadway reconstruction project that expands the hydraulic capacity of culverts in the project area could get credited not only in the resilience category but also for (1) safety enhancements (by reducing the chance of culvert blowouts that can often prove fatal), (2) support of economic growth (especially if the roadway is the primary access road to a critical local business or industrial facility), and (3) congestion reduction benefits (if there are routine major delays due to flooding).

OPERATIONS AND MAINTENANCE ACTIVITIES/PROJECTS

***Consider Resilience Improvements in O&M Activities*:** The O&M units of state DOTs are typically the ones first affected by system disruptions. They are typically called upon to maintain some level of traffic flow and clean up after an incident. The maintenance unit is often tasked with replacing any ancillary assets (e.g., traffic signs,

signals, and guardrails) that have failed from the disruption and to remove debris that often accompanies extreme weather events. The operations unit is often tasked with rerouting traffic around blocked roads and managing evacuation routes in anticipation of or in response to major disasters. There are a host of good practices to consider for enhancing resilience in O&M activities such as these. Some examples include:[5]

- Developing a system whereby O&M staff can report resilience-related problems to other groups within KYTC that might utilize the information for their own functional responsibilities (e.g., asset management). O&M staff could routinely provide after-event reports on the nature of disruptions, the type of response undertaken, and costs and this information could be input into database systems accessible to other units.
- Similar to the above and having the possibility of being combined, coordinating the collection of asset condition data (as part of the asset management program) with ongoing maintenance activities to identify the total cost of recurring asset failure. Recurring failures at one location or of a particular asset (e.g., a culvert) should be factors in the extent, type, and cost of investment that occurs at that location.
- Having contingency plans in the event traffic management systems are disrupted (e.g., alternative ways of providing traveler information when there is a disruption of the electrical grid). Good practice includes having contingency plans for all possible types of system disruptions (e.g., power loss) and having these plans field tested.
- Field exercises and training exercises for O&M staff on the roles they play in overall system resilience. Best practice entails including system resilience in training materials for O&M staff, including in-house field exercises that simulate deployment of O&M resources in response to different types of incidents and disruptions, often in collaboration with partner agencies.
- Periodic review (and archiving) of traffic incident reports, maintenance records, after-action reports, emergency reimbursement forms, and other sources of data to determine how system disruptions have affected performance and agency costs over time. This implies continuing to examine the agency's response to system disruptions from the perspective of internal actions and procedures. For example, is it necessary to revamp work order codes for system disruptions or use other methods to improve tracking of labor, equipment, and materials costs over time?
- Pre-positioning equipment and supplies in areas prone to damage.
- Investing in road weather information systems (RWIS) and real-time and near-term prediction tools for natural hazard impacts (e.g., leveraging the National Water Model for flood impact prediction system-wide).
- Having contracts in place that enable private vendors to come in quickly and augment KYTC staff post-disaster. Periodically reassessing these stand-by support contracts to make sure they are providing the needed capabilities and resources for the types of disruptions being faced.
- Using the Emergency Management Assistance Compact (EMAC), leveraging mutual aid from other DOTs and agencies to augment staff/equipment needs for disasters. Relatedly, establishing Pre-Scripted Resource Requests (PSRRs) under EMAC for anticipated resource needs post disaster. PSRRs will help expedite the provision of mutual aid from other DOTs in the wake of a disaster.

[5] Many of the strategies listed here are from the 2021 NCHRP Report, *Mainstreaming System Resilience Concepts into Transportation Agencies: A Guide*, produced by the same authors.

- Pre-signing detour routes.
- Programming signals along a detour route to operate in a different mode when a detour is in place.
- Developing agreements with local communities on debris removal pre-disaster.
- Pro-active debris clearing from bridges, culverts, stormwater systems, etc.

Periodically Assess O&M Budgets for Adequacy in Promoting Resilience: Evidence from state DOT experience with road disruptions suggests that O&M activities have an important role in avoiding potentially catastrophic failures at individual locations in the road network, or at the network level if the hazard is widespread. KYTC could conduct an analysis periodically, perhaps every other budget cycle, to determine whether O&M budgets are adequate to avoid bigger costs due to lack of resilience in future years. For example, this assessment could enquire whether there is enough budget to remove debris from culverts and otherwise keep them in a state-of-good-repair to prevent more costly future failures.

***Assess the Vulnerabilities of KYTC Equipment and Personnel to Extreme Heat*:** Extreme heat is an important consideration for maintenance personnel and the equipment they and operations staff rely upon. The *Task 1.4 Potential Resilience Strategies* memorandum from this project described some O&M strategies that can be considered by KYTC for extreme heat. For example, many operations assets (e.g., signals and communications, monitoring, and information systems) contain electronics that are sensitive to high temperatures or affected by power supply disruptions. Strategies for dealing with this concern include: (1) examining specifications for operations assets over time to ensure they reflect the changing environmental context relating to higher temperatures, (2) performing regular maintenance checks on cooling devices for electronic equipment (fans, etc.), (3) for mission-critical equipment, consider air conditioning or other strategies to mitigate against heat-related failure, and (4) provisioning emergency electrical backup for facilities considered critical in case of power outage. In addition, where appropriate, KYTC could consider transitioning to solar energy or other energy sources that do not rely on the electric grid for backup. For staff, there are many protocols and procedures that can be implemented to reduce their exposure to dangerous heat while working outside (e.g., more frequent breaks, more night work/shifting of work hours, etc.).

Relate Vulnerability Assessment Outputs to Planned Activities/Projects: As discussed previously, the KYTC Division of Maintenance not only conducts routine non-capital maintenance activities, but it also oversees small capital projects that are aimed at fixing a current problem or avoiding future problems. These small capital projects differ from those explicitly listed in the Enacted Highway Plan capital program not only in size and scale, but also in the process and technical support necessary to construct the projects. For example, there is no need for a DNA, project geospatial data is most often not available, etc.

KYTC O&M staff can leverage the VAST vulnerability assessment results (and, eventually, the risk results) in several ways:

- The results could be used to target where to undertake some of the pro-active resilience activities mentioned above. For example, where to (1) pre-position equipment/materials, (2) target asset cleanings, (3) install RWIS and related monitoring systems, and (4) post detour route signing, etc.
- As with asset management and capacity improvement projects, overlay future small maintenance project locations with the outputs from the vulnerability assessment. As geospatial data on these project locations is not available, this assessment would need to be performed visually on a project-by-project basis. To facilitate this, web-based mapping of the hazard data and vulnerability assessment results could be made available to staff working on these projects along with instructions on how to use it consider possible resilience enhancements.

- Use the results to inform where small capital investments under the Division of Maintenance might be most needed to enhance roadway resilience.

Implement a Program to Conduct Facility-Level Resilience Assessments for Highly Vulnerable Assets: In the Asset Management and Performance Projects section above, a recommendation was offered to conduct facility-level resilience assessments for highly vulnerable assets. Many of these assessments will likely be of a smaller scale such that they fit within the small capital projects undertaken by the Division of Maintenance (KYTC could develop a system to delineate which groups within the agency have responsibility for conducting facility-level assessments for existing assets; this could possibly be done by asset type with guidance/support provided from a resilience team at headquarters). Regardless of who leads, the structured approach to facility-level assessments discussed in the asset management section is recommended. Consistently done BCAs are valuable as part of the process to facilitate prioritization of resilience-focused projects (see below). Note that, for smaller projects like those undertaken by maintenance, more simplified BCAs might be warranted, facilitated by the development of standard analysis templates.

Implement a Program to Prioritize Resilience-Focused Maintenance Projects: As noted in the asset management section, there is likely to be an increasing backlog of resilience-focused small capital projects that outstrips available resources. This is likely to be the case for small capital projects under the purview of the maintenance unit and, indeed, there are indications this may already be happening. Prioritization will need to be done amongst these projects. If each proposed project entails a BCA done with consistent scenarios/assumptions, the BCA outputs could provide a useful means for selecting which projects to invest in. For example, proposed resilience-focused projects could be ranked by their NPVs (ideally, the ones inclusive of user and socioeconomic costs) and their up-front capital costs. Those with the highest NPVs within the established budget could then be included in the analysis. The recommended NPVs provide a convenient metric to capture which projects might generate the most long-running savings to KYTC and Kentucky residents. Other non-monetizable factors could also be considered although this level of analysis may not be warranted for small capital projects led by maintenance.

APPENDIX A: MINNESOTA DEPARTMENT OF TRANSPORTATION APPROACH TO OVERLAYING RISK ASSESSMENT OUTPUTS WITH PLANNED CAPITAL PROJECTS

One of the project tasks for the MnDOT Resilience Improvement Plan (RIP) was to develop and implement an approach for identifying projects that could have a resilience element added to the project scope. This effort leveraged asset-by-asset hazard ratings that were developed for different asset classes (roadways, bridges, culverts, stormwater ponds, catch basins/drop inlets, pump stations, steep slopes, traffic signal systems, intelligent transportation system (ITS) devices, road weather information system (RWIS) devices, weigh-in-motion devices, and automated traffic recorder devices) on the RIP project. These hazard ratings are akin to the outputs of the vulnerability assessments KTC performed and included consideration of hazard exposure and user impacts (i.e., number of users impacted and network redundancy). MnDOT intended to share these hazard ratings, and the data that informed them, with project sponsors/developers so they could, if appropriate, propose enhancements to their projects to address the concerns identified and thereby strengthen the resilience of the projects they manage.

Three important points of departure acted as a foundation for this effort:

- The approach focused on previously planned MnDOT and State Aid[6] projects in the State Transportation Improvement Program (STIP) and Capital Highway Investment Plan (CHIP).
- The methods did not apply to planned projects with new road alignments as the data being used pertains to existing roadways. However, the hazard mapping data developed as part of the RIP could provide useful information for new alignments as much of it has complete coverage throughout the state.
- It was understood that the state's investment program should also include resilience-focused projects (i.e., projects where enhancing resilience is the primary goal). Locations where such projects are needed could be identified from past experience with weather-related impacts and by considering the hazard exposure and rating information across the entirety of the state and state-aid networks.

It was noted that, given the data being used for the vulnerability scores pertains to existing assets, the summary information to be generated for each project should not be interpreted as being an analysis of the planned project design alternative(s) for resilience. For instance, a planned project may already contemplate changes to the road elevation or a bridge design (relative to the asset currently in place) that would address existing risks. It would be up to project sponsors to take the hazard information provided through this process, as it applies to the existing asset, and determine, through project-level assessment, whether the proposed alternatives were sufficient to address changing conditions and, if not, to propose alternative(s) that were.

To undertake the analysis of pipeline projects, planned projects of different types were related to pertinent asset types, their associated hazard ratings (0 [very low], 1 [low], 2 [medium], 3 [high], and 4 [very high]), and the component metrics that was used to develop those hazard ratings. An example below shows how the available metrics were summarized for planned pavement and other linear highway projects on the state system (separate sets of information were compiled for bridge/culvert projects on the state system and state aid projects of any type). Note that the metrics are organized first by asset type they pertain to, then hazard. It

[6] MnDOT's State Aid programs are akin to the local government funding programs administered by the Department of Rural and Municipal Aid

was intended that this information be shared with project managers to use when considering adding resilience enhancements to these types of projects.

- Roadway exposure and hazard rating metrics
    - Temperature
        - Amongst the road segments within the project limits, indicator whether the binder grade for any of the segments would need to change from current MnDOT specifications (Performance Grade 58X-34) for past conditions and, for Shared Socioeconomic Pathway 2 4.5 (SSP2-4.5) and SSP5-8.5, mid-century and late-century
    - Freeze-thaw
        - Amongst the road segments within the project limits, the maximum annual number of days the high temperature is greater than 32° Fahrenheit (F) and the low temperature is less than 32°F for past conditions and, for SSP2-4.5 and SSP5-8.5, mid-century and late-century
    - Precipitation/flooding
        - Presence of any road segments within the project limits within the 100-year floodplain for past climate conditions
    - Winter weather
        - Amongst the road segments within the project limits, the maximum annual precipitation depth on days where the high temperature is less than 32°F for past conditions and, for SSP2-4.5 and SSP5-8.5, mid-century and late-century
        - Amongst the road segments within the project limits, the maximum daily precipitation depth on days where the high temperature is less than 32°F for past conditions and, for SSP2-4.5 and SSP5-8.5, mid-century and late-century
    - Coastal erosion
        - Amongst the road segments within the project limits, presence of any near a portion of Lake Superior shoreline with high coastal erosion potential under past climate conditions
    - Wildfire
        - Amongst the road segments within the project limits, the maximum annual burn probability for past climate conditions
    - Hazard rating
        - Length-weighted average hazard rating amongst the road segments within the project limits
- Bridge and large culvert exposure and hazard rating metrics
    - Temperature
        - Amongst the concrete bridges within the project limits, the maximum bridge high temperature for past conditions and, for SSP2-4.5 and SSP5-8.5, mid-century and late-century
        - Amongst the concrete bridges within the project limits, the minimum bridge low temperature for past conditions and, for SSP2-4.5 and SSP5-8.5, mid-century and late-century
        - Amongst the concrete bridges within the project limits, the maximum difference in bridge high and low temperatures for past conditions and, for SSP2-4.5 and SSP5-8.5, mid-century and late-century

    - Freeze-thaw
        - Amongst the concrete bridges within the project limits, the maximum annual number of days the high temperature is greater than 32° Fahrenheit (F) and the low temperature is less than 15°F for past conditions and, for SSP2-4.5 and SSP5-8.5, mid-century and late-century
    - Precipitation/flooding
        - Amongst the bridges over rivers and streams and large culverts within the project limits, the maximum percentage change in daily precipitation depth in the watershed for the 50-year storm under Representative Concentration Pathways 4.5 (RCP 4.5) and 8.5 during early-century, mid-century, and late-century
    - Coastal erosion
        - Count of bridges and large culverts within the project limits and near a portion of Lake Superior shoreline with high coastal erosion potential under past climate conditions
    - Wildfire
        - Amongst the bridges and large culverts within the project limits, the maximum annual burn probability for past climate conditions
    - Hazard rating
        - Average hazard rating amongst the bridges and large culverts within the project limits
- Pipe (highway and entrance culverts) exposure and hazard rating metrics
    - Precipitation/flooding
        - Amongst the pipes coded as highway culverts within the project limits, the maximum percentage change in daily precipitation depth in the watershed for the 50-year storm under RCPs 4.5 and 8.5 during early-century, mid-century, and late-century
        - Amongst the pipes coded as entrance culverts within the project limits, the maximum percentage change in daily precipitation depth at the asset for the 10-year storm under RCPs 4.5 and 8.5 during early-century, mid-century, and late-century
    - Coastal erosion
        - Count of pipes within the project limits and near a portion of Lake Superior shoreline with high coastal erosion potential under past climate conditions
    - Wildfire
        - Amongst the pipes within the project limits, the maximum annual burn probability for past climate conditions
    - Hazard rating
        - Average hazard rating amongst the pipes within the project limits
- Stormwater pond exposure and hazard rating metrics
    - Precipitation/flooding
        - Amongst the stormwater ponds within the project limits, the maximum percentage change in daily precipitation depth at the asset for the 100-year storm under RCPs 4.5 and 8.5 during early-century, mid-century, and late-century
    - Coastal erosion

        - Count of stormwater ponds within the project limits and near a portion of Lake Superior shoreline with high coastal erosion potential under past climate conditions

    - Hazard rating
        - Average hazard rating amongst the stormwater ponds within the project limits
- Catch basins/drop inlet exposure and hazard rating metrics
    - Precipitation/flooding
        - Amongst the catch basins/drop inlets within the project limits, the maximum percentage change in daily precipitation depth at the asset for the 10-year storm under RCPs 4.5 and 8.5 during early-century, mid-century, and late-century
    - Coastal erosion
        - Count of catch basins/drop inlets within the project limits and near a portion of Lake Superior shoreline with high coastal erosion potential under past climate conditions
    - Hazard rating
        - Average hazard rating amongst the catch basins/drop inlets within the project limits
- Pump station exposure and hazard rating metrics
    - Precipitation/flooding
        - Amongst the pump stations within the project limits, the maximum percentage change in daily precipitation depth at the asset for the 50-year storm under RCPs 4.5 and 8.5 during early-century, mid-century, and late-century
    - Coastal erosion
        - Amongst the pump stations within the project limits, count of those near a portion of Lake Superior shoreline with high coastal erosion potential under past climate conditions
    - Wildfire
        - Amongst the pump stations within the project limits, the maximum annual burn probability for past climate conditions
    - Hazard rating
        - Average hazard rating amongst the pump stations within the project limits
- Slope exposure and hazard rating metrics
    - Freeze-thaw
        - Amongst the slope vulnerability management areas (i.e., those with recommended actions from the slope vulnerability assessment) in the vicinity of the project limits, the maximum annual number of days the high temperature is greater than 32° Fahrenheit (F) and the low temperature is less than 32°F for past conditions and, for SSP2-4.5 and SSP5-8.5, mid-century and late-century
    - Precipitation/flooding
        - Amongst the slope vulnerability management areas (i.e., those with recommended actions from the slope vulnerability assessment) in the vicinity of the project limits, the maximum percentage change in daily precipitation depth at the slope for the 100-year storm under RCPs 4.5 and 8.5 during early-century, mid-century, and late-century
    - Coastal erosion

        - Amongst the slope vulnerability management areas (i.e., those with recommended actions from the slope vulnerability assessment) in the vicinity of the project limits, an indicator of whether any are near a portion of Lake Superior shoreline with high coastal erosion potential under past climate conditions
    - Wildfire
        - Amongst the slope vulnerability management areas (i.e., those with recommended actions from the slope vulnerability assessment) in the vicinity of the project limits, the maximum annual burn probability for past climate conditions
    - Hazard rating
        - Area weighted average hazard rating amongst slope vulnerability management areas (i.e., those with recommended actions from the slope vulnerability assessment) in the vicinity of the project limits
- Traffic signal system exposure and hazard rating metrics
    - Precipitation/flooding
        - Count of signal systems within the project limits and within the 100-year floodplain for past climate conditions
    - Coastal erosion
        - Count of signal systems within the project limits and near a portion of Lake Superior shoreline with high coastal erosion potential under past climate conditions
    - Wildfire
        - Amongst the traffic signal systems within the project limits, the maximum annual burn probability for past climate conditions
    - Hazard rating
        - Average hazard rating amongst the traffic signal systems within the project limits
- ITS device exposure and hazard rating metrics
    - Precipitation/flooding
        - Count of ITS devices within the project limits and within the 100-year floodplain for past climate conditions
    - Coastal erosion
        - Count of ITS devices within the project limits and near a portion of Lake Superior shoreline with high coastal erosion potential under past climate conditions
    - Wildfire
        - Amongst the ITS devices within the project limits, the maximum annual burn probability for past climate conditions
    - Hazard rating
        - Average hazard rating amongst the ITS devices within the project limits
- RWIS device exposure and hazard rating metrics
    - Precipitation/flooding
        - Count of RWIS devices within the project vicinity and within the 100-year floodplain for past climate conditions
    - Coastal erosion
        - Count of RWIS devices within the project vicinity and near a portion of Lake Superior shoreline with high coastal erosion potential under past climate conditions

    - Wildfire
        - Amongst the RWIS devices within the project vicinity, the maximum annual burn probability for past climate conditions
    - Hazard rating
        - Average hazard rating amongst the RWIS devices within the project vicinity
- WIM and ATR device exposure and hazard rating metrics
    - Precipitation/flooding
        - Count of WIM and ATR devices within the project limits and within the 100-year floodplain for past climate conditions
    - Coastal erosion
        - Count of WIM and ATR devices within the project limits and near a portion of Lake Superior shoreline with high coastal erosion potential under past climate conditions
    - Wildfire
        - Amongst the WIM and ATR devices within the project limits, the maximum annual burn probability for past climate conditions
    - Hazard rating
        - Average hazard rating amongst the WIM and ATR devices within the project limits

In addition to providing this granular information to project managers, each planned project was also assigned its own hazard rating. The project hazard ratings were an amalgamation of the average hazard rating metrics amongst the asset classes associated with the project.

MEMO

TO: Tracy Nowaczyk (KYTC)

FROM: Elizabeth Farc (WSP), Chris Dorney (WSP), Carrie Grassi (WSP), and Mike Meyer (independent consultant)

SUBJECT: Task 1.6, Recommendations for KYTC Use of the Emergency Relief Program

DATE: June 13, 2025

This memo presents general recommendations for the Kentucky Transportation Cabinet (KYTC) to consider for using the Federal Highway Administration's (FHWA) Emergency Relief (ER) Program funding, focusing on betterments. The memo begins with an overview of the ER Program and its relationship with resilience. It then details KYTC's utilization of the ER Program and challenges encountered in applying for and managing funding. Recommendations are offered for each challenge identified and for other ER Program considerations as well.

RESILIENCE & THE EMERGENCY RELIEF PROGRAM

PROGRAM OVERVIEW

The program overview that follows includes a review of the ER Program's purpose, eligibility requirements, the distinction made within the program between emergency repairs and permanent restoration, and program cost share requirements.

PURPOSE OF THE PROGRAM

The purpose of the ER Program is to provide funding for the repair or reconstruction of federal-aid highways (the ERFA Program) and federally-owned roads (the ERFO Program) that have experienced major damage from either a natural hazard (e.g., hurricane, flood, earthquake, or wildfire) or a catastrophic failure from an external or man-made cause (e.g., a bridge collapse due to a collision). The ER Program is meant to supplement resources from the states (including the District of Columbia and U.S. territories), their political subdivisions, and federal agencies to help pay for unusually heavy and unexpected expenses resulting from these events. The following information focuses on the requirements, application processes, and trends for the ERFA Program only. Although only a subset of the larger ER Program, ERFA will be referred to as "the ER Program" throughout.[1]

The ER Program is administered through state DOTs in close coordination with the FHWA Division Office in each state. The decision to seek financial assistance under the program is made by state DOTs, not by the federal government. Local officials who wish to seek ER funding do not deal directly with FHWA; they must do so through their state DOTs.

ER funds are not intended to cover all repairs, relieve maintenance responsibilities, or cover work performed prior to the event date. The intent of the program is to restore assets to their pre-disaster condition through either emergency repairs or permanent restoration activities. That said, as noted above, eligibility has been expanded to include allowances to rebuild in a manner that can prevent damage from a future extreme event.

[1] American Association of State Highway and Transportation Officials (AASHTO). A Primer on Resilience Considerations in the Federal Highway Administration's Emergency Relief Program. WSP Task Order "Overview and Guidance on the Federal Highway Administration's Emergency Relief (ER) Program and Resilience Opportunities**".**

This includes the ability to (1) make repairs consistent with current design standards (for assets that had not previously been up to current design standards),[2] or (2) save the FHWA ER Program money over time through enhanced resilience measures that extend and preserve the useful life of the asset (i.e., a betterment).

Disaster-damaged public roads that are not federal-aid highways (or federally owned roads) may be eligible for disaster aid from the Federal Emergency Management Agency (FEMA) Public Assistance Program if there is a Presidential disaster declaration. While FEMA is prohibited from funding permanent repairs on federal-aid highways, under certain circumstances, FEMA funds may be used for emergency work on federal-aid highways such as debris removal. Where applicable, suggestions that may also relate to FEMA applications are noted in the Recommendations section.

PROGRAM ELIGIBILITY

Access to ER funds requires (1) eligibility of the disaster event, and (2) threshold damages across the state. A Governor's disaster proclamation or a U.S. President's disaster declaration must specify the affected area for funding eligibility. The disaster must cause at least $700,000 (federal share) in damages statewide, with individual sites needing a minimum of $5,000 in repair costs. Adjacent locations can be considered collectively if damaged by the same event. The federal-aid highways covered by ERFA are public roads classified as arterials, urban collectors, and major rural collectors. Roads that are classified as minor rural collectors or local roads are not eligible for ER funding even if other federal-aid funds have been used on those roads.

EMERGENCY REPAIRS VS. PERMANENT RESTORATION ACTIVITIES

ER funds are for short-term emergency repairs and permanent restoration. Eligible sites and costs must be identified within two years of the disaster. Emergency repairs, which restore traffic, minimize damage, or protect facilities, can start without FHWA approval. State DOTs can access "Quick Release" funds for initial repair operations before standard applications. These funds assist with urgent repairs in large disasters but not debris removal if FEMA-eligible. Permanent restoration follows emergency repairs and aims to return highways, bridges, or tunnels to their pre-disaster state. These projects need prior FHWA approval and authorization.

COST SHARE REQUIREMENTS

Emergency repairs within 270 days are reimbursed at 100% Federal share. After 270 days, emergency repairs on interstate highways receive a 90% federal share, while other federal-aid highways receive an 80% share. Extensions for the 270-day period are possible if access for evaluation is delayed. Permanent repairs follow the same rules on federal share as emergency repairs. If a state's ER expenses exceed annual federal-aid apportionments, permanent repair shares can increase to 90% for all roads.

PROGRAM HISTORY & RESILIENCE POLICY

The Hayden-Cartwright Act of 1934 authorized federal funds for disaster-damaged road repairs, requiring states to use regular apportioned funds without new funding. The Federal-Aid Highway Act of 1956 created the ER Program with $30 million annually and a 50% federal cost share. By 1979, it was funded solely through the Highway Trust Fund (HTF) with a permanent $100 million annual authorization. The Surface Transportation Assistance Act (STAA) of 1982 capped ER funds at $30 million per state per disaster, raised to $100 million by the 1987 Surface Transportation and Uniform Relocation Assistance Act (STURAA,) and removed by Moving Ahead for Progress in the 21st Century Act (MAP-21) in 2012. The ER Program evolved to reimburse repairs to

[2] Map-21 – Moving Ahead for Progress in the 21st Century: Emergency Relief (ER) Questions and Answers, FHWA. August 8, 2013. https://www.fhwa.dot.gov/map21/qandas/qaer.cfm

current design standards and allow upgrades above these standards if shown to save money—known as "betterments."

In November 2021, the Bipartisan Infrastructure Law (BIL), part of the Infrastructure Investment and Jobs Act (IIJA), authorized $1.2 trillion for transportation and infrastructure spending, including $550 billion for new investments and programs. For the ER Program, BIL continued the $100 million per year authorization from the HTF and added several expansions:

1. Included wildfire as an eligible natural disaster.
2. Allowed improvements that mitigate future repair costs due to extreme weather and other natural disasters.
3. Expanded protective features, such as raising roadway grades, relocating floodplain roadways, stabilizing areas, lengthening or raising bridges, increasing drainage structures, seismic retrofits, and using natural infrastructure.

The BIL also redefined a comparable facility to include economically justifiable improvements to mitigate recurring damage risks. It mandated FHWA to develop best practices for resilience in the ER Program and track its implementation. Consequently, FHWA's website now includes case studies on successful betterment implementations by state DOTs.[3]

BASELINE RESILIENCE REIMBURSEMENT

This section begins with a discussion of the importance of design standards in establishing baseline resilience reimbursement levels. It then presents a comparative analysis of the hydrology and hydraulic (H&H) design standards established by KYTC, as well as its baseline Emergency Relief (ER) Program reimbursement levels for flooding—the hazard most associated with ER Program-eligible damages—with those of other states.

THE IMPORTANCE OF DESIGN STANDARDS

Permanent repairs are undertaken after a disaster to restore a roadway to its pre-disaster condition or, if a betterment is being considered, to a condition that is better able to survive future stresses. KYTC must follow a process to get permission for construction of permanent repairs.[4] Permanent repairs typically require submittal of a Letter of Intent to FHWA on the following information:

- "Development of plans, specifications, and estimates
- Some design effort
- Geotechnical studies or other engineering studies
- Structural analysis
- Environmental reviews
- Utility assessments"

FHWA responds to the Letter of Intent with acknowledgment of among other things:

- "Preliminary engineering

[3] https://www.fhwa.dot.gov/programadmin/er/casestudies.cfm

[4]Kentucky Transportation Center (KTC). 2024. Federal Highway Administration (FHWA) Emergency Relief (ER) Program. Knowledge Portal. Accessed at https://kp.uky.edu/knowledge-portal/articles/federal-highway-administration-fhwa-emergency-relief-er-program/. Last accessed March 31, 2025.

- Guidance for permanent work
- Time frame and items needed for Damage Survey Summary Report
- Time limit for programming
- Payment contingent on approval by the FHWA Division Administrator
- Record keeping requirements"

As can be seen from this abbreviated list, presentation of design concepts and, thus, design standards are part of both a KYTC ER submittal as well as the response from FHWA. Given the importance of preliminary and final engineering designs in ER project development, one of the key starting points for developing ER applications is the baseline design guidelines and standards that will reflect the type and level of resilience improvements that could be incorporated into the repairs. This is especially true for H&H guidelines and related design standards which tend to more explicitly state standards than some other engineering disciplines. In addition, federal ER guidance notes that state DOTs can use non-federally approved design standards for ER projects if, in fact, they are more stringent than the minimums recommended by federal agencies for federal-aid highways (see **Table 1** for minimum H&H design standard guidance cited by FHWA).

Table 1: Minimum Design Event Guidelines for Roads, Bridges, and Culverts Cited in AASHTO Drainage Manual

Roadway Classification	Exceedance Probability (%)	Return Period (Years)
Interstate, Freeways (Urban/Rural)[a]	2%	50
Principal arterial	2%	50
Minor arterial, ADT > 3,000 vpd	2%	50
Minor arterial, ADT <= 3,000 vpd	4%	25
Collector, ADT > 3,000 vpd	4%	25
Collector, ADT <= 3,000 vpd	10%	10
Local road[b]	20-10%	5-10

ADT: Average daily traffic VPD: Vehicles per day

[a] Federal regulation requires Interstate highways to be provided with protection from the two percent flood event. Underpasses and depressed roadways should also be designed to accommodate the two percent flood. Where no embankment overflow relief is available, drainage structures should be designed for at least the one percent or 100-yr event.

[b] At the discretion of the designer, based on Risk Analysis and Design Hourly Volume (DHV).

Source: AASHTO. 2014. AASHTO Drainage Manual, Volume 1- Chapter 9 Hydrology, Washington DC: AASHTO

The AASHTO drainage manual notes that for culverts and bridges the hydraulics designer should use a "review flood frequency" (representing an overtopping flood or base flood) as part of the analysis when:

- The culvert is in a FEMA National Flood Insurance Program mapped floodplain to confirm that the backwater caused by the culvert would not exceed 1ft over the existing base (100-yr flood elevation), and when
- A risk assessment or analysis of the culvert is required by federal regulations.

Table 1 presents the minimum design flood events. The drainage manual notes in the bridge chapter that "design floods for such factors as the evaluation of backwater, clearance, and overtopping should consider a risk-based assessment of local site conditions. The risk assessment should reflect consideration of traffic

service, environmental impact, property damage, hazard to human life, and floodplain management criteria." In addition, "hydraulic design will normally be for at least a 10-yr flood on local rural road bridge replacement projects with an overflow section in the approach grade. Bridge replacement projects on non-state highway rural collector roads and urban collector streets will normally be designed to pass at least the 25-yr flood. If the ADT is less than 100, a 10-yr flood is recommended."

In reality, many state DOTs use the 100-year design event for bridges, and the 500-year event for assessing scour.

COMPARISON OF KYTC HYDROLOGY & HYDRAULIC DESIGN STANDARDS TO OTHER DOTS

WSP conducted a review of state DOT H&H design procedures and standards for the American Association of State Highway and Transportation Officials (AASHTO) as part of a task order called *Overview and Guidance on the Federal Highway Administration's Emergency Relief (ER) Program and Resilience Opportunities,* a project looking at the ER Program nationally. **The purpose of this review was to establish the baseline for ER Program permanent repairs in each state and, through this, be able to define more specifically what constitutes a betterment in each state.** This enabled an assessment into how much the definition of a betterment varies across states. Some general observations from the assessment are worth noting before comparing how KYTC's H&H design standards compare to other states:

- In most cases, flexibility in applying H&H design guidance and design standards is recommended practice (i.e., "should," "may," and "could" language) not a requirement (not "shall," or "must" language). In those cases where flexibility is allowed, designers are strongly encouraged to look at a wide range of annual exceedance probability (AEP) events. Much is left to the judgement of the designer, although in all cases the State Hydraulics Engineer or Office must review and approve.
- In some cases, especially where design guidance has been most recently updated, state DOTs have acknowledged that many design standards and guidance documents are based on past trends and experience and are challenged by future conditions that might be very different
- Many states define their H&H design events by road functional classification, in which higher classified roads such as an interstate road would use a more stringent design event in recognition of the importance of that road
- There is quite a bit of variance on bridge design standards between the Table 1 minimum design event guidelines and what states are doing (the standards for bridges are higher, often 100 and 500-year events). Furthermore, there is notable variance between states. Some say use the 100-year for hydraulic opening, others use something less like the 50-year (often compensating with more freeboard, but not always). The differences among the states with respect to H&H culvert design guidelines is most likely due to the varying topographical and meteorological contexts to which culverts may be more sensitive. For example, some states that typically face large snow melt-related peak flows (e.g., North Dakota) have gone beyond the federal minimum design guidance for culverts (e.g. use of a 100-year storm versus a 50-year storm).
- FHWA's Highway Engineering Circulars (HEC; especially *HEC-17: Highways in the River Environment-Floodplains, Extreme Events, Risk, and Resilience*; *HEC-19: Highway Hydrology: Evolving Methods, Tools, and Data*; and *HEC-23: Countermeasure Design for Bridge Scour & Stream Instability*) are identified as important references, and in some cases, as required procedures.
- Many state DOTs are following the lead or requirements of state environmental agencies (or coastal commissions in the case of sea level rise) in providing special design consideration in areas that are considered vulnerable to changing future conditions. In some cases, gubernatorial executive orders,

often accompanied by state laws, have motivated state DOTs to examine their internal procedures and processes to identify how they can better consider resiliency to future conditions in their day-to-day actions.

- A few states (e.g., Virginia) mentioned that they are considering the use of modified intensity-duration-frequency (IDF) curves in future H&H work. No state DOT referenced using such curves currently.

Table 2 compares KYTC's H&H minimum design standards with national standards as defined by FHWA and in comparison, to other states as found in the AASHTO review referenced above. As shown in the table, KYTC's H&H design standards are consistent with the standards cited in HEC-17. As also shown, some states have adopted more stringent standards for interstates, principal arterials, and minor arterials with higher traffic volumes.

The KYTC Drainage Manual provides some flexibility to designers in applying these standards and there is also a recognition that there are different accepted methods for estimating the return period events and that these can result in different flow estimates. The recommended methods for both hydrological and hydraulic analysis fall into three levels organized in ascending level of effort:

- "LEVEL 1 - Qualitative assessment involving the application of hydrologic, hydraulic, and geomorphic factors to identify potential problems and alternative solutions for bridges. Perform hydrologic analysis and field survey (i.e. bridge opening, roadway profile, stream profile, hydraulic sections, etc.).
- LEVEL 2 - Quantitative analysis combined with a more detailed qualitative assessment of the hydrologic, hydraulic, and geomorphic factors of the stream --- generally includes water surface profile and scour calculations.
- LEVEL 3 - Complex quantitative analysis based on detailed mathematical modeling and possibly physical hydraulic modeling. This analysis is necessary only for high-risk locations, extraordinarily complex problems, and after-the-fact analyses where losses and liability costs are high."

As noted in federal regulations, the difference in levels reflect "where site conditions or structural requirements substantially limit practicable design alternatives, the conventional hydraulic analysis coupled with a risk assessment should meet the requirements of the design standards. Where site conditions permit a range of design alternatives and flood losses are anticipated, an abbreviated or partial risk analysis may be appropriate (level 2). We would anticipate that use of the full scale detailed economic (risk) analysis (level 3) as described in HEC-17 would not be necessary for normal stream crossings, but would apply to unusual, complex, or high-cost encroachments involving flood losses."

In some circumstances, other design constraints (e.g., compliance with NFIP, state DOT, or other requirements) often preclude the effective application of the minimum design guidelines shown in **Table 1**. In such circumstances, the Drainage Manual requires that each bridge project analysis include a risk assessment evaluating the use of different return periods that reflect the individual programmatic requirements of the applicable law or regulation.

Table 2: Comparison of KYTC, Federal, and Other State Minimum Design Guidance for Hydrologic and Hydraulic Design

	Min. FHWA Recommended Standard		KYTC Standard (Return Period)	Mode From National State DOT Review	Largest Value Found in a State DOT Guidance
	Exceedance Prob. (%)	Return Period (years)			
Interstate Freeways	2%	50 yrs	50 yrs	50 yrs	100 yrs
Principal Arterial	2	50	50	50	100
Minor Arterial, ADT > 3,000 vpd	2	50	50	50	100
Minor Arterial, ADT <= 3,000 vpd	4	25	25/10*	25	Not classified
Collector, ADT > 3,000 vpd	4	25	25/10*	25	10
Collector ADT <= 3,000 vpd	10	10	25/10*	10	Not classified
Local road	20 to 10	5 to 10	N/A	N/A	N/A

* KYTC distinguishes between roads with < 400 vpd (10-year return period) and roads < 2,000 but > 400 vpd (25-year return period)

ADT: Average daily traffic VPD: Vehicles per day

Source: KYTC. Drainage Manual. Accessed at https://transportation.ky.gov/Highway-Design/Drainage%20Manual/DR%20400%20Hydrology%20(%202012).pdf

BETTERMENTS TO FUND RESILIENCE UPGRADES

As noted above, a betterment is an added protective feature or change that modifies the function or character of a facility from what existed prior to the disaster and agency design standards and that could economically reduce the cost of future damage. For this type of work to be eligible for ER funding, the state DOT must demonstrate that the up-front cost of the protective feature would be less than the costs that would be incurred by the ER Program for future damages should the betterment not be constructed. The analysis cannot include other factors often included in highway benefit/cost evaluations such as user costs (e.g., traffic delay costs, added fuel costs, etc.), motorist safety, economic impacts, etc. as those factors do not relate to ER Program eligible costs.

While FHWA requires an economic analysis to justify the use of ER funds for betterments, there is a lack of clear guidance on the FHWA ER Program website on how to perform this analysis. The clearest guidance is found on FHWA's Federal Lands ERFO website.[5] While there are some differences in eligibility and responsible parties between the ERFO and ERFA programs, the guidance that is presented appears to be applicable to both programs. According to the online step-by-step tutorial, the primary components of the economic analysis are the:

1. Cost of the betterment
2. Likelihood and severity of future ER eligible damage
3. Cost to repair future damage both with and without the betterment

Each of these elements is discussed below.

[5] Emergency Relief: Understanding Betterment Eligibility and Approval, FHWA. https://flh.fhwa.dot.gov/programs/erfo/training/eligibility/

COST OF THE BETTERMENT

The cost of the betterment is determined by subtracting the total cost of the project without the betterment (the baseline cost) from the total cost of the project with the betterment. The baseline cost to be used is for replacement-in-kind, not the default ER replacement that meets current design standards (which, in some cases, might be more resilient and have higher costs). The cost estimate should include all costs to develop and construct the alternatives including environmental compliance, preliminary engineering, construction engineering, construction, traffic control, and permits.

LIKELIHOOD AND SEVERITY OF FUTURE EMERGENCY RELIEF-ELIGIBLE DAMAGE AND COST TO REPAIR FUTURE DAMAGE

A life-cycle analysis that includes both the likelihood of future ER eligible damage and the cost to repair future damage can satisfy the required economic justification. The tutorial describes two methods (and provides accompanying spreadsheet templates) for evaluating the life-cycle cost of alternatives:

1. *"Historic Approach* - Historic records are primarily used to estimate the frequency and severity of future damage. The present worth of expected future repairs, with credit given for remaining service life, plus the initial project delivery cost are used to determine the alternative with the lowest cost (i.e., the preferred alternative).
2. *HEC-17 Approach* (i.e., Hydraulic Engineering Circular No. 17) - The probability and expected damage associated with an array of possible flood events are used to generate an annual economic risk. The present worth of the annual series over the service life of the alternative plus the initial project delivery cost is used to determine the alternative with the lowest cost."

Both methods consist of eight discrete steps:

1. Document past and current damage
2. Establish alternatives
3. Estimate future damage severity
4. Estimate cost to repair damage
5. Select analysis period and service life
6. Select discount rate
7. Compute lifecycle costs
8. Analyze results

Note that there is no provision for projections of changing future conditions to be used in the methods/spreadsheets provided. Indeed, the tutorial acknowledges that it presents a simplified approach to meeting the economic justification requirement of the ER Program. It suggests that,

> "….it may be beneficial to use a probabilistic-based risk analysis such as a Monte Carlo Simulation for high-cost critical infrastructure. For example, an analysis that considers hydrodynamic factors such as tides, storm surge, wind, waves, river discharge, coastal geometry, bathymetric effects, and possibly future climate scenarios can be developed. Each of the factors are assigned an appropriate probability distribution that is randomly sampled to create a discrete economic result and then the process is repeated over and over again."[6]

[6] Ibid.

However, no additional guidance is presented on this type of analysis. WSP has developed a Climate Risk Assessment (CRA) Tool for FHWA that accomplishes what is discussed. As of the date of this publication, that tool has not yet been released.

KYTC USE OF THE ER PROGRAM

According to KYTC's Resilience Improvement Plan, KYTC's emergency repair database contains records from 2009 onwards detailing occurrences of transportation system damage due to extreme weather events. Most issues arise from heavy rains causing flash floods, rockfalls, erosion, embankment failures, and debris flows, especially in eastern Kentucky's mountainous areas.[7] **Table 3** shows ten events from 2015-2024 and that totaling nearly $164.5 million in ER funding. This is more than double the median state total allocation value of $78.9 million across the 46 other states and five territories that received ER funds for extreme weather events in that same period.

In 2019, KYTC developed a GIS-based system to track and monitor ER events, including data since 2009 involving FHWA reimbursement. The system identified 563 ER locations, with the majority of funds spent in eastern Kentucky, though incidents occurred statewide (**Figure 1**). This system helps KYTC coordinate repairs in line with 23 CFR Part 667. So far, 19 sites have been repeatedly damaged, primarily in Districts 11 and 12, possibly missing betterment opportunities.

Table 3: Events in KY Prompting Use of ER Funds, 2015-2022

Event Date	Event Year	Event Description	Event Code	Event Fiscal Year	Event Total Allocation to Date
March 5	2015	Storms and Statewide Flooding	KY15-1	2015	$7,312,701
July	2015	Storms and Flooding	KY15-2	2015	$3,654,016
March/April	2017	Flooding	KY17-1	2017	$1,300,000
February 9	2018	Severe Storms and Flooding	KY18-1	2018	$26,707,455
February 6	2019	Severe Storms and Flooding	KY19-1	2019	$45,889,014
February 3	2020	Severe Storms and Flooding	KY20-1	2020	$27,963,005
February 27	2021	Severe Storms - Flooding, Landslides, and Mudslides	KY21-2	2021	$23,929,685
December 10	2021	Severe Storms Straight-line Winds Flooding and Tornadoes	KY22-1	2022	$3,693,800
December 31	2021	Severe Storms Straight-line Winds Flooding and Tornadoes	KY22-2	2022	$2,025,312
July 26	2022	Storms and Flooding	KY22-3	2022	$22,000,000

[7] Kentucky Transportation Cabinet (2023, July). *Transportation Resilience Improvement Plan.* https://www.erm-portal.com/wp-content/uploads/sites/15/2023/03/KYTC-Resiliency-Improvement-Plan-bf0967c098d35794c9ad19448450184e.pdf

District	Total Costs
1	$2,555,000
2	$2,052,600
3	$420,387
4	$2,062,307
5	$458,500
6	$3,191,500
7	$500,637
8	$698,284
9	$3,055,197
10	$2,009,500
11	$25,038,000
12	$9,599,493

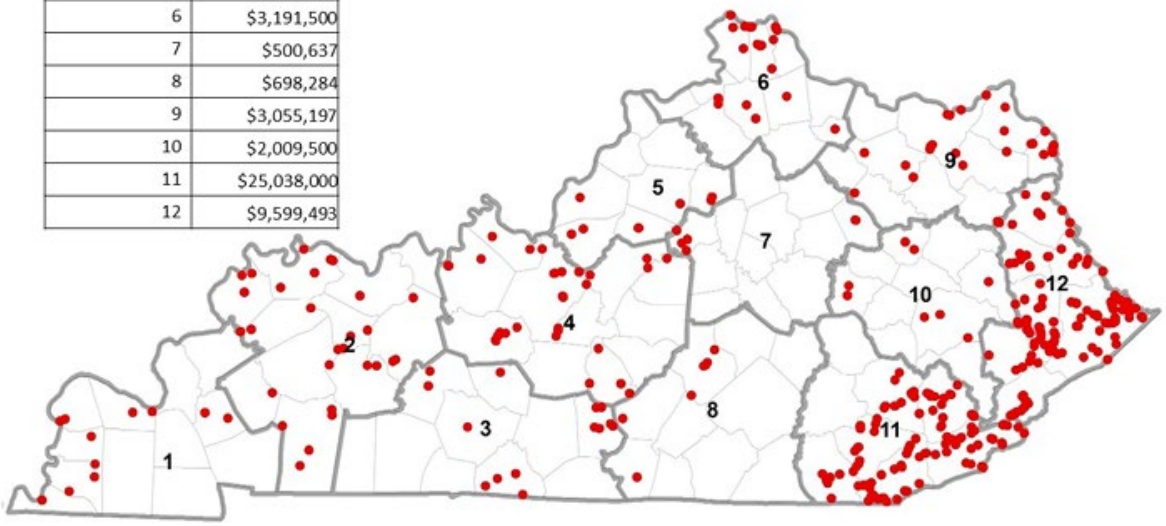


Figure 1: Locations and Total Costs by KYTC district of ER events from 2009-2018.
Source: Asset Management, Extreme Weather, and Proxy Indicators (2019).

The Kentucky Transportation Center (KTC) is currently engaged in research utilizing data on historical transportation system damages to better understand future likelihoods of such incidents. Data from the emergency repair database is being integrated with historical weather data, including daily precipitation and temperature records, to develop a probabilistic model of extreme weather and roadway damages. Although this research effort is ongoing, preliminary results suggest that this model can be used alongside data on changing future conditions to assist in long-range planning for transportation system damages associated with hazards.

OBSERVED CHALLENGES AND RECOMMENDATIONS

Challenges in applying for and administering ER Program funds were discussed during the KYTC Leadership Discussions for this project. A summary of the input follows along with associated recommendations:

- **Challenge:** There are currently separate spreadsheets between the FHWA ER and FEMA Public Assistance reimbursement programs, which present administrative challenges. A more unified approach between FHWA and FEMA for reimbursement could be beneficial.
    - **Recommendation:** Differences in using the FEMA Public Assistance and FHWA ER Programs is a long-running complaint amongst several DOTs. To resolve this, consider working with other states through AASHTO's Committee on Transportation System Security and Resilience (CTSSR) to encourage better alignment between the two programs. However, until the broader structural challenges can be resolved, consider having the same department manage both programs, but with different sets of staff focused on each. Louisiana DOT used this "divide and conquer" approach with success.
- **Challenge:** There is a need for improved record-keeping and documentation for reimbursement funding and understanding existing conditions. Recently, training has been rolled out, and it is

essential that more people are informed and understand the terminology. Disseminating language and information on the various federal disaster recovery programs to staff is critical.

  - **Recommendation:** Continue with the training program and expand it to include training on betterments. Betterments are a great opportunity to procure additional funding to help enhance resilience in known impacted areas. To take maximum advantage of the funding opportunities offered by the ER Program, KYTC should build the capabilities to make consideration of forward-looking betterments routine for any damaged asset that is ER-eligible. Through discussions on this project, it was noted that KYTC has never formally applied for a betterment and, consequently, staff experience with them is limited. Part of the training on betterments might include training on how to consider changing future conditions, where to obtain data projecting those conditions, and how to tie them into betterment design. Given that they may be used in betterment applications, using future condition projections might very well enable KYTC to enhance the resilience of the replacement asset designs even further. Consider the possibility of augmenting internal capabilities as well with on-call/standby contracts to assist with betterment applications when disaster strikes.

- **Challenge:** Personnel in the field must be equipped with the proper tools during response efforts to gather initial information on damage and communicate effectively. Efforts to mainstream the use of FHWA's Mobile Solution for Assessment and Reporting (MSAR) at KYTC are a big step in that direction.
  - **Recommendation:** Leverage the data collected through MSAR for use in KYTC's broader resilience program. Consider augmenting the data captured in the application with additional attributes on (1) the damaged asset (e.g., design storm), extreme weather event (e.g., return period of storm/flow rate, etc.), (2) forensics on how and why the asset failed (with searchable codes for common causes of failure, not just the narrative description currently included which is hard to search), (3) impacts to the traveling public (noting injuries/fatalities, asset downtime, traffic impact metrics, etc.), (4) and additional details on the replacement asset (e.g., whether a betterment was included, level of resilience included, etc.). Use this data to improve decisions on design standards over time and to inform the refinement of damage functions for use in resilience benefit-cost assessments. Ensure a linkage between the damage reports and the asset management program so that repeat damaged assets are flagged and that asset managers know to update their databases to include the replacement asset (replacing the record for the damaged asset).

- **Challenge:** A post-disaster feedback loop is needed to intentionally identify issues and address them for future events. This includes learning from major disasters by examining failures and their causes, capturing institutional knowledge, and improving responses to future incidents. Additionally, feedback on design parameters is needed to assess how designs respond to events and diagnose asset failures.
  - **Recommendation:** In addition to using an enhanced MSAR as recommended above, consider participating in and contributing to regular peer exchanges on DOT lessons learned from natural disasters. There are many insights to be gained and best practices to consider on resilience and disaster response beyond Kentucky's border. AASHTO's CTSSR can provide a forum for this exchange. In fact, the CTSSR has an action item to set up annual peer exchanges from DOTs that experienced disasters to share lessons learned. Should this be stood up, consider becoming a regular participant. KYTC might also consider holding their

own annual internal peer exchange amongst all the districts to share experiences, lessons learned, and best practices.

Some additional recommendations on use of the ER Program include:

- Consider the use of an on-call/standby contracts (or other existing in-place contract vehicles) to help with damage inspections, documentation, paperwork, and managing finances for both the ER and FEMA Public Assistance Programs. Other states have successfully used such contracts to increase manpower on a temporary basis and provide specialized expertise post-disaster. Consider dividing the contracts up by districts so as not to have one contractor addressing the entire state. Experience in other states has shown it is often better to utilize multiple contracts so there is no slow down from capacity issues should an event impact multiple districts.
- In addition to on-call/standby contracts, consider augmenting ER and FEMA Public Assistance compliance needs with mutual aid support from DOTs (and other public agencies) from around the country using the Emergency Management Assistance Compact (EMAC). AASHTO has a project underway to develop EMAC-compliant templates to facilitate resource sharing around disasters. Many of these templates are likely to focus on damage assessments and other resource needs surrounding the ER Program. AASHTO offers opportunities to participate in this process and shape the development of the templates. The 2025 Southern Association of State Highway and Transportation Officials Annual Meeting will be held in Lexington in Summer 2025 and is likely to feature a workshop on the templates. AASHTO is also likely going to be offering an opportunity to develop state-specific services to customize these templates to each state's needs.
- Undertake facility-level assessments (inclusive of resilience economic analyses) for at-risk assets during "blue sky" (non-storm) conditions to identify cost-effective betterments. Have those designs and analyses in a database and ready to be used should a disaster strike. This will help to expedite the recovery process and encourage the use of betterments (which can be difficult to undertake when there is a push to restore service as quickly as possible).
- Consider stockpiling certain materials (e.g., jersey barriers, AquaDams, culverts of varying dimensions) to save time post-disaster. For example, Louisiana developed a standardized "major submerged road package" that they were able to implement quickly for relevant damage locations. The ER Program was used to reimburse some costs once the materials were used on applicable ER-funded projects, and the department was able to reuse some of the response materials in subsequent emergencies.