KENTUCKY TRANSPORTATION CENTER
176 Raymond Building, University of Kentucky
859. 257. 4513 www.ktc.uky.edu

Transportation System Vulnerability and Resilience to Extreme Weather Events and Other Natural Hazards

Report for Pilot Project — KYTC District 1

Kentucky Transportation Center Research Report — KTC-16-20/SPR16-524-1F
DOI: http://dx.doi.org/10.13023/KTC.RR.2016.20

KTC's Mission

We provide services to the transportation community through research, technology transfer, and education. We create and participate in partnerships to promote safe and effective transportation systems.

Kentucky Transportation Center
176 Oliver H. Raymond Building
Lexington, KY 40506-0281
(859) 257-4513

www.ktc.uky.edu

Research Report
KTC-16-20/SPR16-524-1F

Transportation System Vulnerability and Resilience to Extreme Weather Events and Other Natural Hazards

Report for Pilot Project — KYTC District 1

By
Benjamin Blandford, PhD
Research Scientist, Kentucky Transportation Center

Scott Schurman
Environmental Project Manager, Kentucky Transportation Cabinet

Candice Wallace, PhD
Research Associate, Kentucky Transportation Center

and

Sarah McCormack, MSC CTL
Research Scientist, Kentucky Transportation Center

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

In cooperation with
Kentucky Transportation Cabinet
Commonwealth of Kentucky

September 2016

Executive Summary

This research's objective is to assist the Kentucky Transportation Cabinet (KYTC) in its efforts to develop strategies to address natural hazard vulnerabilities and improve the resiliency of Kentucky's transportation infrastructure. Recent federal legislation calls for state transportation agencies to develop a risk-based asset management plan for National Highway System (NHS) assets that includes consideration of 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.

This report consists of two parts:

- An overview of vulnerability assessments and natural hazards for KYTC. This is intended to inform and guide transportation system vulnerability assessments for Kentucky.
- Pilot vulnerability assessment for the National Highway System in KYTC District 1. The District 1 pilot adopts a framework for conducting the assessment for particular locations. Lessons learned from the District 1 pilot project will direct future assessments in the remaining KYTC districts.

This research reviewed FHWA guidance on transportation vulnerability assessments and climate change. Vulnerability assessment frameworks used by other state transportation agencies, including the Washington State Department of Transportation (WSDOT) and Tennessee Department of Transportation (TDOT), were also reviewed. From this guidance, the project team developed a vulnerability assessment framework focused on acquiring and analyzing available data related to natural hazards and their impact on the transportation system. This data component is complemented by workshops held in KYTC Districts to integrate local expert knowledge into the assessment. Based on these two components transportation assets are ranked and/or flagged for significance in terms of vulnerability to natural hazards.

Considerable effort for this project was spent identifying potential natural hazards and transportation system vulnerabilities. Meteorological hazards analyzed include flooding, tornados, wind, hail, winter storms, extreme heat, drought, wildfire, fog, and freeze/thaw cycles. Geological hazards, include earthquakes, landslides, and sinkholes. Each of these natural hazards can negatively impact the transportation system by triggering disruptions, damage, or potentially destruction. The magnitude of negative impacts, however, varies considerably from hazard to hazard. To narrow this assessment's focus to the hazards with the largest overall impacts, a survey was conducted of KYTC officials to identify perceptions of vulnerability to each of these hazards. The survey results indicated that KYTC personnel think that earthquakes, flooding, landslides, and sinkholes are most likely to negatively impact the transportation system. These survey results guided the direction of the District 1 vulnerability assessment.

In addition to the data collected pertaining to particular hazards, a second subset of data was acquired pertaining to historical climate trends and future climate projections. County-level historical climate data for Kentucky were obtained from the Midwest Regional Climate Center (MRCC). These data contained records of extreme precipitation, temperature, and wind events. The data also identified trends associated with freeze/thaw cycles in the state. The obtained historical climate data only goes back to 1980; as such, identifying definitive temporal trends was not possible. However, mapping these data revealed significant geographic trends across the state that are useful for understanding what locations are most vulnerable to extreme weather events.

The District 1 pilot vulnerability assessment focused on transportation system vulnerability to flooding, earthquakes, landslides, and sinkholes. The assessment consisted of existing research on these hazards, analysis of existing data, and completion of a workshop with KYTC District 1 officials and engineers. Data from a series of KTC reports on the seismic vulnerability of bridges and embankments were compiled and mapped. Landslide and sinkhole data were acquired from the Kentucky Geological Survey. FEMA floodplain maps and KYTC maintenance records were used to identify NHS assets vulnerable to flooding. The workshop conducted in District 1 to elicit local expert information on transportation system vulnerability supplemented the data analysis.

Primary findings from the District 1 pilot assessment include NHS highway segments, bridges, culverts, and other structures that are vulnerable to natural hazards. These are summarized in the table below:

Hazard	Indicator	Miles of NHS	Bridges	Culverts	Structures
Earthquake	PGA zone > 120	13	7	1	0
Earthquake	PGA zone > 80	13.4	6	4	0
Earthquake	PGA zone > 60	85	20	7	39
Earthquake	50 yr event – KTC vulnerability studies	-	24	-	-
Flood	100 yr Floodplain	28.9	79	18	3
Flood	D1 Workshop	-	12	4	3
Karst	KGS Karst Major	60.9	10	2	27
Karst	KGS Karst Moderate	0	0	0	0
Landslide	KGS Landslide Inventory	(3 hwy locations)	4	0	0
Landslide	USGS Landslide High	12.7	7	1	0
Landslide	USGS Landslide Moderate	0	0	0	0

Secondary findings include the identification of two towns, Ledbetter and Wickliffe, that are vulnerable to losing highway system access and being cutoff were severe flooding to occur. The worst case scenario for District 1 would entail concurrently experiencing a major seismic event and a major river flood.

Table of Contents

List of Figures

List of Tables

1. Introduction

The Kentucky Transportation Cabinet (KYTC) owns and maintains billions of dollars of transportation-related assets across the Commonwealth of Kentucky. While this transportation infrastructure has been designed to handle a broad range of climatic impacts based on historic observations and trends, less is known about how the system will respond to potential impacts from extreme weather events and other natural hazards. These issues can pose a significant threat to the safety, reliability, effectiveness, and sustainability of transportation infrastructure and operations. Examples of extreme weather events in Kentucky include sustained higher temperatures; intense, prolonged downpours and subsequent flooding; and high wind events associated with thunderstorms and tornadoes. Climate change projections show there is a higher likelihood of each of these weather phenomena over the coming decades. Geologic hazards in Kentucky include earthquakes, sinkholes, and landslides. Each of these hazards has the potential to affect the lifecycle of transportation systems, resulting in higher maintenance costs and shorter replacement cycles.

In December of 2014, the Federal Highway Administration (FHWA) issued Order 5520, which holds it is the FHWA's policy to "integrate consideration of climate and extreme weather risks into its planning, operations, policies and programs". [1] The directive instructs state transportation agencies to evaluate and then implement risk-based, cost-effective strategies to minimize risks associated with climate change and extreme weather and protect critical infrastructure using the best available science, technology, and information. This Order supplements MAP-21 (and continued through the FAST Act) requirement that state agencies develop a risk-based asset management plan for the National Highway System (NHS).[2]

This project's objective was to develop a pilot process for assessing the vulnerability of KYTC assets to natural hazards, including geological hazards and extreme meteorological events. This 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 that identifies KYTC's assets that are at risk from extreme weather events;
c) Identify the assets that are most vulnerable 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 on planning, design, operations, and maintenance processes.

The output of the pilot process includes a GIS-based data system compatible with existing Cabinet systems. The extent of the pilot includes the assessment of the NHS as defined by MAP-21. For this pilot project, the scope of the assessment is limited to NHS assets in KYTC's

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

District 1. District 1 includes the following 12 counties of western Kentucky: Ballard, Calloway, Carlisle, Crittenden, Fulton, Graves, Livingston, Lyon, Marshall, Hickman, McCracken, and Trigg. However, the assessment process has been formulated so it can be replicated to evaluate NHS assets for all KYTC Districts.

The project results are intended to directly inform the Cabinet's efforts to develop a risk-based asset management plan, as required by MAP-21. The results will also enhance KYTC's efforts to fulfill requirements set out by the FHWA directive on transportation system preparedness and resilience to climate change and extreme weather events.

2. Transportation Vulnerability Assessments

FHWA Order 5520 establishes the agency's policy on climate change and extreme weather event preparedness and resilience. The order mandates that FHWA identify risks associated with climate change and extreme weather events and to incorporate consideration of these risks into planning, operations, and maintenance of the nation's transportation system. The directive also encourages state transportation agencies to develop, prioritize, implement, and evaluate risk-based and cost-effective strategies to minimize the adverse effects of climate change and extreme weather events on critical infrastructure.[3]

For this project, the FHWA guidance was used to identify the key components for Kentucky's vulnerability assessment. Other state vulnerability assessments, specifically, those conducted by Washington State Department of Transportation (WSDOT) and Tennessee State Department of Transportation (TDOT), also informed the project.[4] The following subsections identify and define the critical concepts incorporated into this project.

2.1. FHWA Guidance

FHWA's *Climate Change and Extreme Weather Vulnerability Assessment Framework*[5] provides guidance that state transportation agencies can use to perform vulnerability assessments. FHWA identifies a set of tasks which should be part of this assessment. These include: 1) gathering and integrating data and information on asset location, characteristics, and climate sensitivities; 2) collecting data on historical weather events and climate change projections; 3) combining asset and climate information to identify vulnerabilities; and potentially 4) assigning the level of risk climate change and natural hazards pose to the assets.

2.1.1. Identifying Scope and Objectives

Vulnerability assessments begin with a research team clearly identifying project objectives. This clarifies the level of detail that will be needed for subsequent analysis and products. Identifying objectives may require identification of the end products' target audience and how it will use them.

Once the objectives have been settled, researchers must decide which transportation assets to include in the assessment. This narrows the scope and makes the assessment a manageable project within the given time and budgetary constraints. Data needs and constraints should be included in any selection of transportation assets at this stage.

Another issue that informs the process of selecting transportation assets is a consideration of their criticality. *Criticality* is the relative importance of an asset within the overall transportation system. FHWA defines criticality as "a filter for screening the universe of assets in a particular geographic area so that the resulting list can be evaluated for exposure, sensitivity, and adaptive capacity."[6]

---

[3] ICF International, "Integrating Climate Change into the Transportation Planning Process"; ICF International, "Climate Change Vulnerability Assessment, Risk Assessment, and Adaptation Approaches"; FHWA, "Assessment of the Body of Knowledge on Incorporating Climate Change Adaptation Measures into Transportation Projects."

[4] FHWA, "FHWA Climate Change Resilience Pilots Peer Exchanges."

[5] FHWA, "Climate Change & Extreme Weather Vulnerability Assessment Framework."

[6] FHWA, "Assessing Criticality in Transportation Adaptation Planning."

Criticality relates to an asset's physical characteristics, such as its replacement value, and its function in the transportation system (e.g., an emergency response route, evacuation route, average annual daily traffic, and/or key commercial route).

FHWA identifies three approaches for assessing criticality: desk review, stakeholder solicitation, and a hybrid approach:[7]

- A *desk review* emphasizes objective and easily obtainable empirical data to use in asset ranking. Where possible, already existing prioritization schemes are used, such as average daily traffic, functional classification, and expert judgment. Advantages of this approach are that it is transparent and easily replicable.
- *Stakeholder solicitation* utilizes expert knowledge of transportation assets provided by local officials or authorities. This can be achieved through a series of focus groups to elicit feedback on the criticality of assets. Advantages of this approach are that it encourages buy-in from relevant stakeholders and promotes collaboration and communication among stakeholders and those likely to implement adaptation strategies.

These can also be combined into a hybrid approach that incorporates both a desk review and stakeholder solicitation. This strategy generally begins with a desk review to identify a list of possible critical assets and the relevant data pertaining to them. It then incorporates this information within the stakeholder solicitation process to inform and structure feedback from stakeholders and local experts.

2.1.2. Assessing Vulnerability

Once the scope and objectives have been resolved and the selection of assets has been completed, the next stage is to develop the vulnerability assessment. The goal of the assessment is to determine how the hazards may impact the transportation assets included in the study. The findings of the assessment can then be used to prioritize specific measures to address these vulnerabilities.

A vulnerability assessment is a process that identifies, quantifies and prioritizes or ranks the vulnerability in the transportation system. This requires an understanding of the ways in which the identified transportation assets can be impacted by extreme weather events and other natural hazards. FHWA identifies several ways to approach this analysis.[8] The first is to consult engineering design standards and guidelines as they pertain to the transportation system. The second is to consider case studies. Case studies should look to address the following points:

- Identify specific events that have caused damage or disruption
- Identify assets that have been impacted by extreme weather events
- Identify thresholds at which the transportation system may begin to experience adverse impacts from severe weather

A third type of analysis is to solicit expert opinion from local officials who are most familiar with the transportation assets under consideration. Local officials can answer such questions as:

---

[7] Ibid.

[8] FHWA, "Climate Change & Extreme Weather Vulnerability Assessment Framework."

- Which roadway segments are prone to flood events?
- What weather conditions produce flooding?
- Had pavement been damaged previously by extreme or prolonged high temperature events?

Collecting data on assets and hazards is also central to a vulnerability assessment. The specific type of data gathered should relate directly to the assessment's objectives. Hazards data serve as inputs to the analysis, whereby different scenarios of varying magnitude and probability can be evaluated. This requires an examination of historical data and projected climate change. FHWA identifies several approaches to incorporate hazards data into the analysis:[9]

- Modeling — Requires climate forecast models of temperature, precipitation, and where applicable, sea level rise.
- Scenarios — Applies a set of scenarios that represent the range of outcomes associated with the future projections.
- Extreme Values — Identifies specific temperature and precipitation thresholds at which adverse impacts are likely to result.
- Estimating river flooding from heavy precipitation — Incorporates flood modeling into the projected climate scenarios and determines the extent of impacts on transportation assets

Other factors to consider for the vulnerability analysis are the issues of probability and risk. Probability refers to the likelihood that a particular scenario or extreme event both occurs and impacts transportation assets included in the study. Risk refers to the magnitude of damage or destruction that would likely occur as a result of the hazard. The contributions of probability and risk can be combined in the overall vulnerability assessment (Table 1). The color of box shading in Table 1, ranging from red (highest vulnerability) to white (lowest vulnerability), denotes the combined effects of probability and risk.

[9] Ibid.

Table 1. Qualitative evaluation of likelihood and consequence of hazardous events.[10]

Likelihood	**Consequence**				
	1.Catastrophic	**2.Major**	**3.Moderate**	**4.Minor**	5.Insignificant
A. Very likely	1A	2A	3A	4A	5A
B. Likely	1B	2B	3B	4B	5B
C. Medium	1C	2C	3C	4C	5C
D. Unlikely	1D	2D	3D	4D	5D
E. Very unlikely	1E	2E	3E	4E	5E

In this analysis, impacts are defined as follows:

- Catastrophic – Huge financial losses; permanent damage and/or long-term loss of service across a sizeable region; long-term impact on commercial revenue
- Major – Major financial losses; some long-term impacts on services; infrastructure damage requiring extensive repair
- Moderate – High financial losses for multiple owners; disruption of services for several days; widespread infrastructure damage requiring maintenance and repair
- Minor – moderate financial losses for small number of owners; disruption of services for a day or two; localized infrastructure damage
- Insignificant – no infrastructure damage; minimal financial losses; short-term inconvenience

Table 1 demonstrates that the severity of the impacts is weighted slightly more heavily than probability. For example, the box *1D* represents an unlikely event, but because the impacts would be catastrophic, the box still receives a higher vulnerability score. Conversely, box *5A* is a scenario that is very likely, but it receives a low vulnerability score because impacts would be insignificant.

2.2. Washington State DOT Climate Impacts Vulnerability Assessment

The Washington State Department of Transportation (WSDOT) was one of five state transportation agencies to receive federal grants as part of FHWA's Climate Change Vulnerability Assessment Pilot Program to test a conceptual climate risk assessment model that was developed specifically for transportation infrastructure.[11] WSDOT applied the model using scenario planning, which involved conducting a series of statewide workshops. Workshop participants, which included local subject matter experts in a variety of fields (such as design engineers, planning, environmental, and maintenance), qualitatively assessed the vulnerability of WSDOT assets to climate extremes. WSDOT adopted an asset management approach to its vulnerability assessment. A qualitative analysis was chosen for numerous reasons — it provides

[10] ICF International, "Climate Change Vulnerability Assessment, Risk Assessment, and Adaptation Approaches."
[11] WSDOT, "Climate Impacts Vulnerability Assessment."

a preliminary understanding of an issue, enables analysis when the only available information is experience and subjective opinions, proves useful when quantitative analysis is beyond the scope an investigation, and it provides a quick assessment.

An interview conducted with members of the WSDOT project steering committee identified a number of key lessons learned from workshop development and data gathering. In the first round of workshops, WSDOT project members identified two main errors that were avoided in subsequent workshops. First, the presenters focused too much time and resources on climate science rather than focusing on gathering local knowledge. Second, in this first series of workshops participants spent too much time focusing on the details of specific assets. That is, too much time was spent on the minutiae. This resulted in the workshop taking too long to complete and participants losing interest and time to devote to the endeavor. The strategy initially adopted by WSDOT focused heavily on details of specific assets and mile points. WSDOT eventually hit on a more meaningful approach to data collection — roads were divided into segments and subsequently analyzed. In addition to describing the methodology and purpose of the workshop to participants, it was imperative to stress the qualitative nature of the data gathering exercise them, and that as such they bore no legal liability for information they provided during the workshop.

After analyzing roadway segments, a question was posed to workshop participants that yielded significant dividends. This question was "What keeps you up at night?" This question got to the heart of what workshop participants thought about hazard vulnerabilities, and what the most pressing district concerns were.

2.3. Tennessee State DOT Vulnerability Assessment

As part of FHWA's Phase II of Climate Change Resiliency Projects, Tennessee State Department of Transportation (TDOT) was selected to conduct a transportation infrastructure vulnerability assessment for climate change and extreme weather events. In 2015, TDOT completed its assessment, *Assessing the Vulnerability of Tennessee Transportation Assets to Extreme Weather*.[12] Because of Tennessee's proximity to Kentucky, as well as its similar array of geologic features and climate conditions, the TDOT assessment was helpful in designing an assessment project for Kentucky.

TDOT's assessment looked at a range of transportation assets. The asset inventory included roads (interstate, state, and U.S. highways), railroads, rail yards, navigable waterways, ports, locks, bridges over navigable waterways, airport runways, maintenance and salt facilities, TDOT buildings (administration, operations), transit facilities (transfer hubs, terminals, fleet storage), and pipelines (oil and natural gas). TDOT developed criteria for determining the criticality of each asset. Criticality was based on factors such as volume of activity, strategic importance, use as an emergency response route, redundant capability, network connectivity, local knowledge and experience.

Transportation assets were evaluated for their vulnerability to a variety of extreme weather events, including extreme heat and cold, wind, tornadoes, hydrologic events (heavy rain, flash

---

[12] Abkowitz, Camp, and Dundon, "Assessing the Vulnerability of Tennessee Transportation Assets to Extreme Weather."

flooding, flooding), lightning, hail, drought, and winter storms. Historical data on these hazards (dating to 1950) were drawn from the National Weather Service's Storm Events Database.

Information about historical climate trends and projected climate change were combined with stakeholder feedback to rank transportation assets' vulnerability to extreme weather events. Stakeholders included representatives from a range of governing agencies, economic sectors, transportation modes, geographic regions, and political jurisdictions. Stakeholder focus group meetings were held in each of TDOT's four regions to inform the assessment and develop vulnerability rankings for transportation assets.

2.4. KYTC's Assessment Design

FHWA guidance documentation, as well as the insights from other state DOT vulnerability assessments, was used to develop this project design. One major departure in this project's design from the aforementioned studies was the inclusion of natural hazards beyond those associated with extreme weather events and climate change. Many areas in Kentucky are susceptible to geologic hazards (e.g., earthquakes, landslides, and sinkholes). Including these hazards benefits KYTC's efforts to develop a risk-based asset management plan.

Meteorological data used in this assessment were obtained from a number of sources. The Midwest Regional Climate Center provided county-level historical climate data. These data captured extreme heat events, precipitation events, and wind events, as well as freeze/thaw cycles. State-level historical climate information dating to 1895 were obtained from the Kentucky State Climate Center. Climate change projection data were acquired from the North American Climate Assessment Program and the Climate Change Institute at ORNL.

One component of the assessment involved compiling existing data pertaining to the current condition of NHS assets. One source for this data was FHWA's National Bridge Inventory (NBI).[13] This dataset, which includes all bridges on public roads in the U.S., aggregates structure inventory and appraisal data collected to fulfill the requirements of the National Bridge Inspection Standards.[14] NBI data record bridge location as well as the condition of bridge structures, substructures, channels, waterways, and culverts.

Another source of data was research reports completed by the Kentucky Transportation Center which assessed the seismic vulnerability of bridges, embankments and other structures in western Kentucky. This research included an evaluation of over 400 bridges along interstates and parkways in western Kentucky, separate assessments of highway embankments, and an in-depth assessment of large-span bridges in western Kentucky.

A third component of data collection was soliciting expert input from local transportation officials. As part of this research, a workshop was held at KYTC's District 1 offices in Paducah, KY. The workshop was designed to develop a systematic ranking of the criticality and vulnerability of the district's NHS assets. The choice to focus on NHS assets was deliberate, and there were two main reasons for doing so. First, MAP-21 provisions required state transportation agencies to develop a risk-based asset management plan for the NHS. Focusing vulnerability assessments on the NHS will let KYTC improve its understanding of the risks that

[13] FHWA, "National Bridge Inventory (NBI)."
[14] FHWA, "Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges."

natural hazards present to NHS assets. In turn, KYTC can develop a more targeted and accurate risk-based asset management plan. Secondly, by focusing the assessment solely on the NHS, it allowed a small, manageable set of transportation assets to be evaluated. Lessons learned from this pilot workshop could be used to improve data collection efforts during future workshops. As the pilot process was developed, a goal was to ensure the assessment process could be easily replicated to allow future assessments of KYTC's other 11 districts. The process was developed so that KYTC could also use it to assess the vulnerability of transportation assets outside the NHS.

At its outset, workshop participants were provided with a keypad system and presented with environmental impact scenarios for segments of the NHS. Participants then ranked each scenario on a scale from 1-9, where a *1* means that the environmental impact on a transportation segment is minimal while a *9* indicates a very significant impact. For example, if an environmental impact were to close a particular segment and there were no alternative routes, the roadway segment would receive a 9 on the criticality scale for that scenario. Keypad rankings were conducted in real time. Participants were able to view the results immediately. If the rankings varied significantly, a group discussion followed to explore why diverging opinions existed, and if necessary, another ranking was done to reflect these conversations.

The District 1 vulnerability assessment had three components:

- Compilation of existing data and research on vulnerability
- Conducting the KYTC district workshop to elicit local expert input
- Identifying and prioritizing the most vulnerable assets and critical scenarios based on existing data and feedback obtained during the workshop

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. Identifying and resolving vulnerabilities was the primary goal of this vulnerability assessment.

3. National Highway System in Kentucky

The National Highway System (NHS) is a strategic network of roadways designated by FHWA for its importance to the nation's economy, defense, and mobility. The NHS includes the following subsystems of roadways:

- Interstate Highway System
- Principal Arterials — those that provide access to major ports, airports, terminals, and intermodal facilities
- Strategic Highway Network (STRAHNET) — highways that are important to the nation's defense system and provide access, continuity, and emergency capabilities for defense purposes
- Major connectors between the three systems noted above

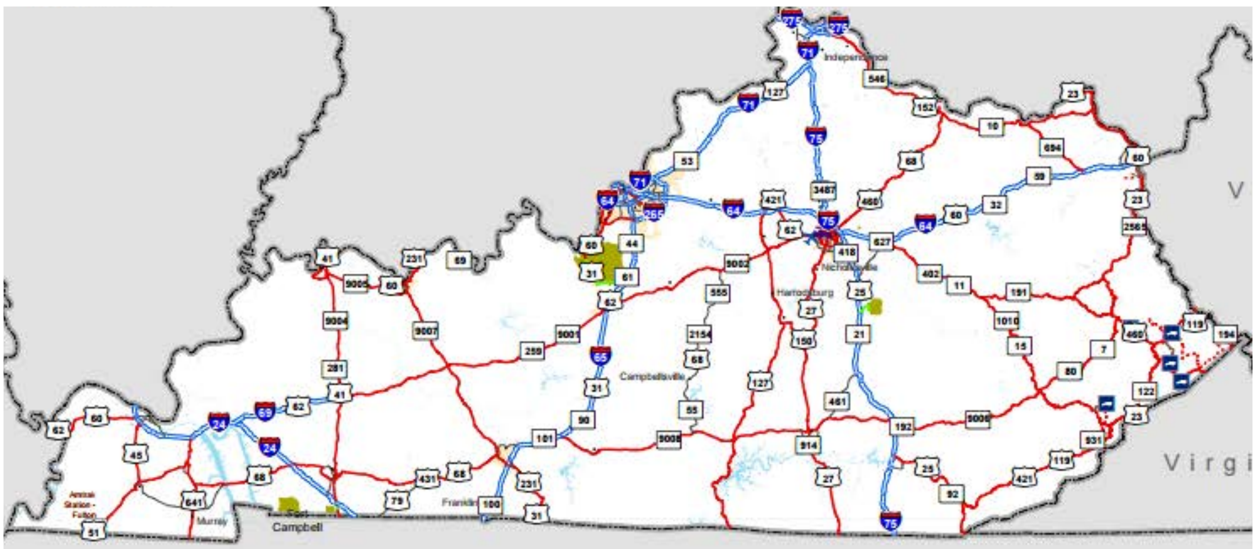


Figure 1. National Highway System in Kentucky

MAP-21 required state transportation agencies to develop a risk-based asset management plan for the NHS. These plans should contain a program that helps states achieve their goals with respect to asset condition and performance. MAP-21 mandated that states address issues related to pavements and bridges and encouraged them to include all transportation assets associated with the NHS. Results of this project will help direct KYTC's efforts to develop this required asset management plan.

4. Identification of Hazards

4.1. Meteorological Hazards

Kentucky is centrally located in the southeastern United States approximately halfway between the Gulf of Mexico to the south and the Great Lakes to the north, as well as between the Atlantic Ocean to the east and the Great Plains to the west. This centrality influences Kentucky's climate, which is marked by its distinct seasonality — with hot summers and cold winters. The annual mean temperature in Kentucky is just above 56˚F, and the state annually receives on average 50" of precipitation.[15]

Kentucky is occasionally affected by the extremes of these winter and summer seasons. In winter, polar air masses can descend from the north resulting in temperatures falling below 0˚F. In summer, tropical air masses can rise up from the Gulf of Mexico resulting in extreme heat and humidity. Kentucky receives plentiful precipitation throughout the year, thanks in large part to the confluence of weather forces that draw up moisture from the Gulf of Mexico. Kentucky also experiences severe thunderstorms, wind, hail, heavy precipitation, and tornadoes, which most frequently occur in the spring and summer. The state also occasionally experiences severe winter storms (e.g., heavy snowfall or ice events).

4.1.1. 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 — 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.[16]

The two types of flooding that 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 result from 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.

Kentucky is particularly vulnerable to flooding. There are over 90,000 miles of streams in the state.[17] The worst recorded flood on the Ohio River in Kentucky occurred was the Great Flood

[15] NOAA National Climatic Data Center, "State Annual and Seasonal Time Series."
[16] The National Severe Storms Laboratory, "Floods."
[17] KGS, "Water Fact Sheet."

of 1937, which impacted the entire river system from Pittsburgh, Pennsylvania to Cairo, Illinois. In Louisville, the river crested at a record 30’ above flood stage. Nearly 70 percent of the city was flooded, and 175,000 people fled their homes. The entire city of Paducah was evacuated.[18] In all, 385 people died in the flood, and damages were estimated to be $250 million.[19] Flooding in May 1997 severely impacted Kentucky. Flooding occurred throughout the state, and 101 out of 120 counties were declared federal disaster areas.[20] The floods resulted in 67 deaths and over $1 billion in damages.

Flash flooding can also impact areas throughout the state, but it is especially problematic in eastern Kentucky, where rugged terrain funnels water down slopes and into stream channels in the valleys. This results in rapid rise of water levels and extremely swift currents. In 2015, torrential rainfall in Johnson and Rowan counties resulted in flash flooding that killed four people and damaged or destroyed over 600 homes.[21] Flash flooding deaths are often directly related to transportation. Approximately 50 percent of flash flood fatalities occur when vehicles stall in flooded roadways and vehicle occupants are swept away in the currents.[22]

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.[23] 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. Figure 2 depicts locations in Kentucky that lie within the 100-year floodplain.

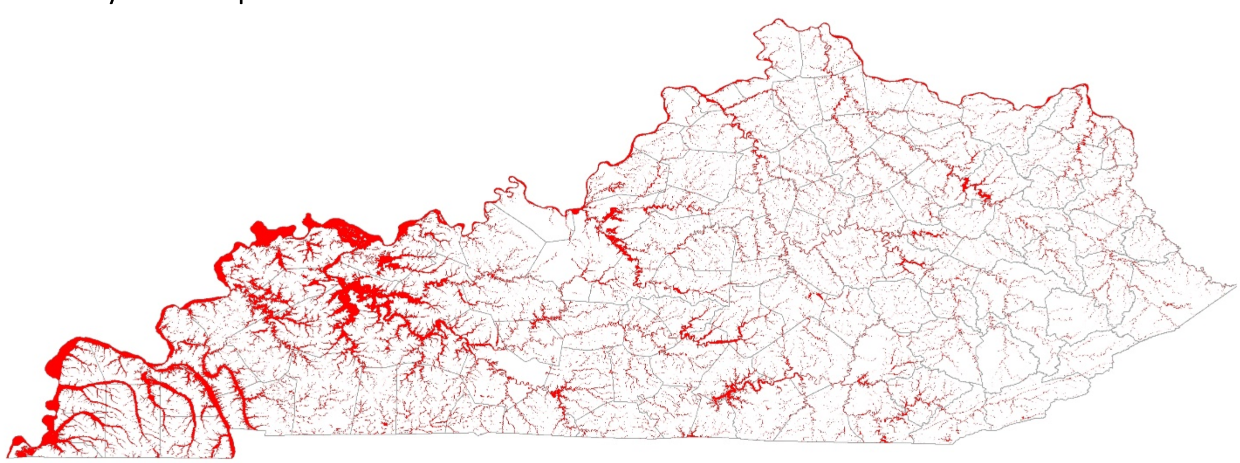


Figure 2. 100-year floodplain map of Kentucky.

[18] Sander and Conner, “Fact Sheet: Ohio River Floods.”
[19] NWS, “The Great Flood of 1937.”
[20] Sander and Conner, “Fact Sheet: Ohio River Floods.”
[21] Moody and Linden, “Dramatic Flash Flooding Turns Deadly in Kentucky.”
[22] KYEM, “Commonwealth of Kentucky Enhanced Hazard Mitigation Plan.”
[23] FEMA, “FEMA Flood Map Service Center.”

Table 2 summarizes KYTC maintenance expenditures for flood work and repairs for fiscal year 2015. Total expenditures were nearly $700,000. Every district had flood-related maintenance expenses.

Table 2. KYTC maintenance expenditures for flood work and repairs, FY 2015.

KYTC District	Flood Work & Repairs
1	$51,678
2	$107,556
3	$24,156
4	$39,093
5	$100,118
6	$29,841
7	$32,742
8	$12,827
9	$148,352
10	$56,519
11	$32,808
12	$57,998
ALL	$693,688

4.1.2. Tornadoes

The National Severe Storms Laboratory defines a tornado as a narrow, violently rotating column of air that extends from the base of a thunderstorm to the ground.[24] Tornadoes occur throughout the world and in every state in the U.S. Though they are more common in the spring and summer, they can occur any time throughout the year. An average of 21 tornados impact Kentucky each year.[25]

The Enhanced Fujita (EF) scale is used to measure tornado intensity. This scale estimates tornado wind speed, based on analysis of damage caused by the tornado. EF0 tornadoes are the lowest intensity, with wind speeds less than 86 mph, while EF5 tornadoes are the most intense, with wind speeds greater than 200 mph.[26] Extremely powerful EF5 tornadoes in Kentucky are rare, though not unprecedented, events. Since 1950, Kentucky has experienced one EF5 tornado, which occurred during the April 4, 1974 Super Outbreak of tornadoes. Three other EF5 tornadoes associated with the 1974 Super Outbreak occurred just north of Kentucky's border with Indiana and Ohio. Kentucky has experienced nearly 20 EF4 tornadoes

[24] The National Severe Storms Laboratory, "Tornado Basics."
[25] KYEM, "Commonwealth of Kentucky Enhanced Hazard Mitigation Plan."
[26] The National Severe Storms Laboratory, "Tornado Basics."

since 1950, the most recent in 2012. Overall, Kentucky has over 1,000 tornadoes have occurred in Kentucky since 1960 with total losses estimated at over $1 billion.[27]

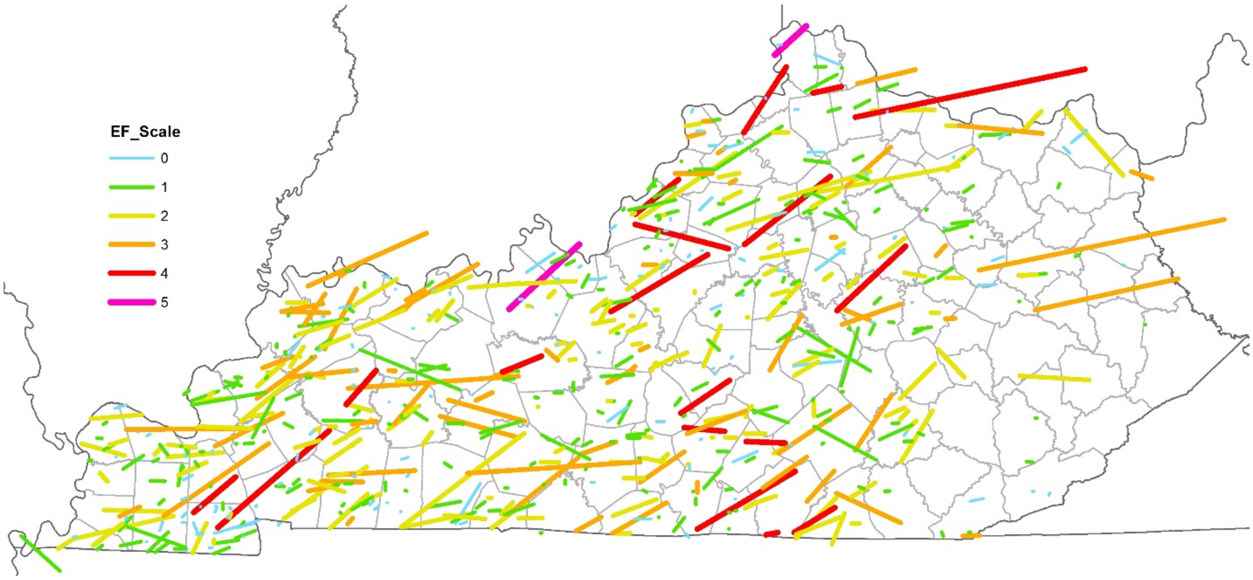


Figure 3. Tracks of all tornadoes that occurred in Kentucky, 1950-2015.[28]

Tornadoes can occur throughout Kentucky, although the Ohio River Valley appears particularly vulnerable to them. Since 2005, a Major Disaster Declaration has been issued 10 times after a tornado occurrence in Kentucky, including twice in 2015. While tornadoes are a fairly regular occurrence in Kentucky and damage from tornadoes can be extensive, their impacts on the transportation system are usually minimal and temporary. Damage or destruction of highway signage and signalization are the most likely effects. Debris in the roadway from structures, utilities, and trees may temporarily disrupt traffic. Tornadoes pose a significant threat to vehicles directly in the tornado's path, as vehicles can be tossed around by the storm.

In rare instances of extremely powerful tornadoes, the transportation system may incur more significant damage (e.g., impacts to the structural integrity of bridges or overpasses). For example, in 2013 an historic bridge along US 62 in Newcastle, Oklahoma was damaged beyond repair by a tornado, which ripped a section of the bridge off its mounts.[29] In 2011, FHWA made $1.5 million in emergency funds available to the state of Alabama to repair the transportation system after a super outbreak of tornadoes in the state.[30]

[27] KYEM, "Commonwealth of Kentucky Enhanced Hazard Mitigation Plan."
[28] NOAA, "Storm Prediction Center Warning Coordination Meteorologist's Page."
[29] National Weather Service, "The Tornado Outbreak of May 20, 2013."
[30] United States Department of Transportation, "FHWA Releases Emergency Relief Funds for Tornado-Damaged Alabama Roadways."

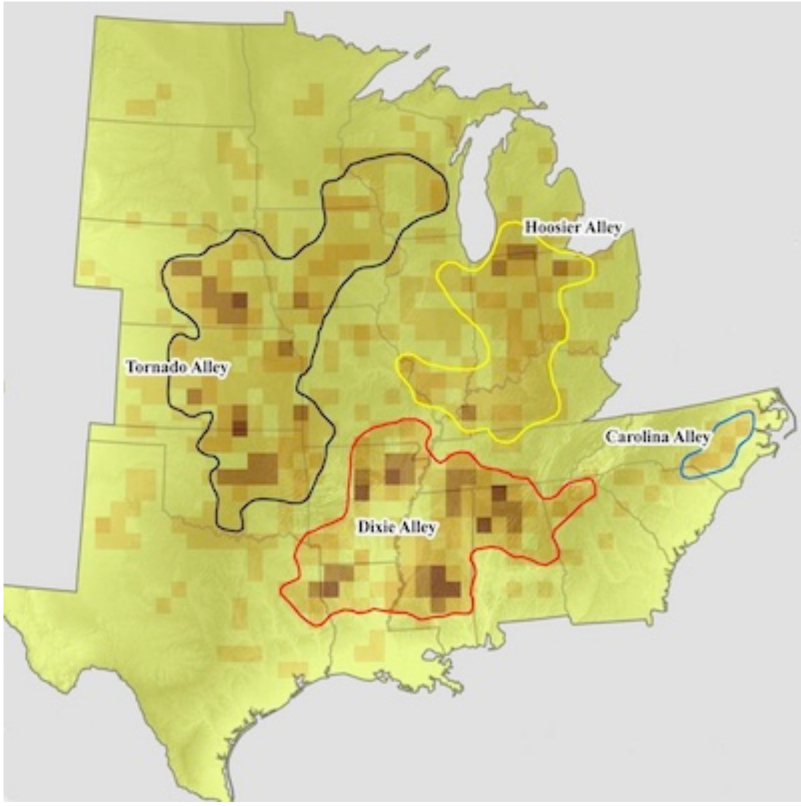


Figure 4. Delineated tornado alleys, based on the frequency of F3-F5 long-track tornados per cell. [31]

4.1.3. Wind

Kentucky is located in an area of the U.S. that is vulnerable to significant wind events. Wind events in Kentucky generally occur as part of a broader severe weather events. The most violent type of windstorms, tornadoes, are covered in a separate section of this report. Thunderstorms pose a significant hazard in Kentucky, and they may generate downbursts or straight line winds.

In rare events, a derecho may produce extreme winds. A derecho is characterized by a swath of wind damage extending for more than 240 miles and including wind gusts of at least 58 mph along most of its length, and several, well-separated gusts of 75 mph or higher.[32] In stronger derechos, winds may exceed 100 mph. In June 2012, a derecho roared across the Ohio Valley and Mid-Atlantic. Parts of northern and eastern Kentucky were affected by this derecho, though the most significant damage occurred farther north and east in Illinois, Indiana, Ohio, West Virginia, Virginia, and Maryland. Though the top wind speeds from this event were relatively low compared to more severe storms, the damage was significant. Over five million people lost power across the region. Twenty-two people were killed, including a man in Clark County, Kentucky who was struck by a falling tree.[33]

---

[31] Frates, "Demystifying Colloquial Tornado Alley."
[32] Corfidi, Evans, and Johns, "About Derechos."
[33] Furgione, "The Historic Derecho of June 29, 2012."

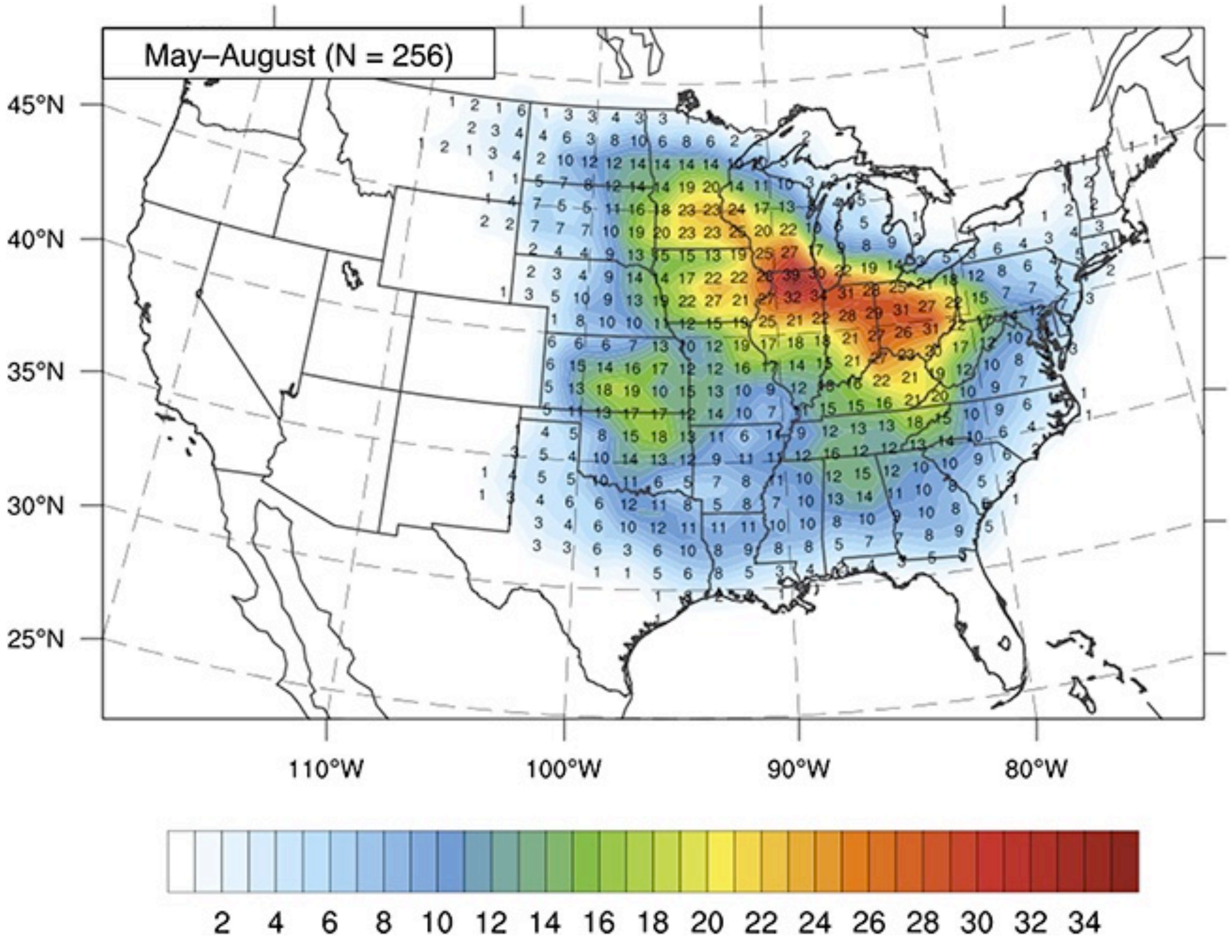


Figure 5. Heat map of derecho likelihood in the U.S.[34]

Though located far from the ocean, wind damage from tropical cyclones occasionally occurs in Kentucky. In September 2008, Hurricane Ike made landfall along the U.S. Gulf Coast. As the storm moved inland, it became an extratropical system and merged with an existing low pressure system. The storm moved northeastward from Texas up the Mississippi River Valley, and then into the Ohio River valley. Hurricane force winds (≥ 74 mph) affected much of western, central, and northern Kentucky, causing significant damage and destruction. The Louisville International Airport and the Cincinnati-Northern Kentucky International Airport were temporarily closed due to power outages and wind damage.[35]

Damage from heavy winds is comparable to that from tornadoes. Often the best way to determine whether the source of damage was a tornado or straight line wind is to examine the pattern of damage on the ground.

4.1.4. Hail

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.

[34] Guastini and Bosart, "Analysis of a Progressive Derecho Climatology and Associated Formation Environments."
[35] Berg, "Tropical Cyclone Report: Hurricane Ike."

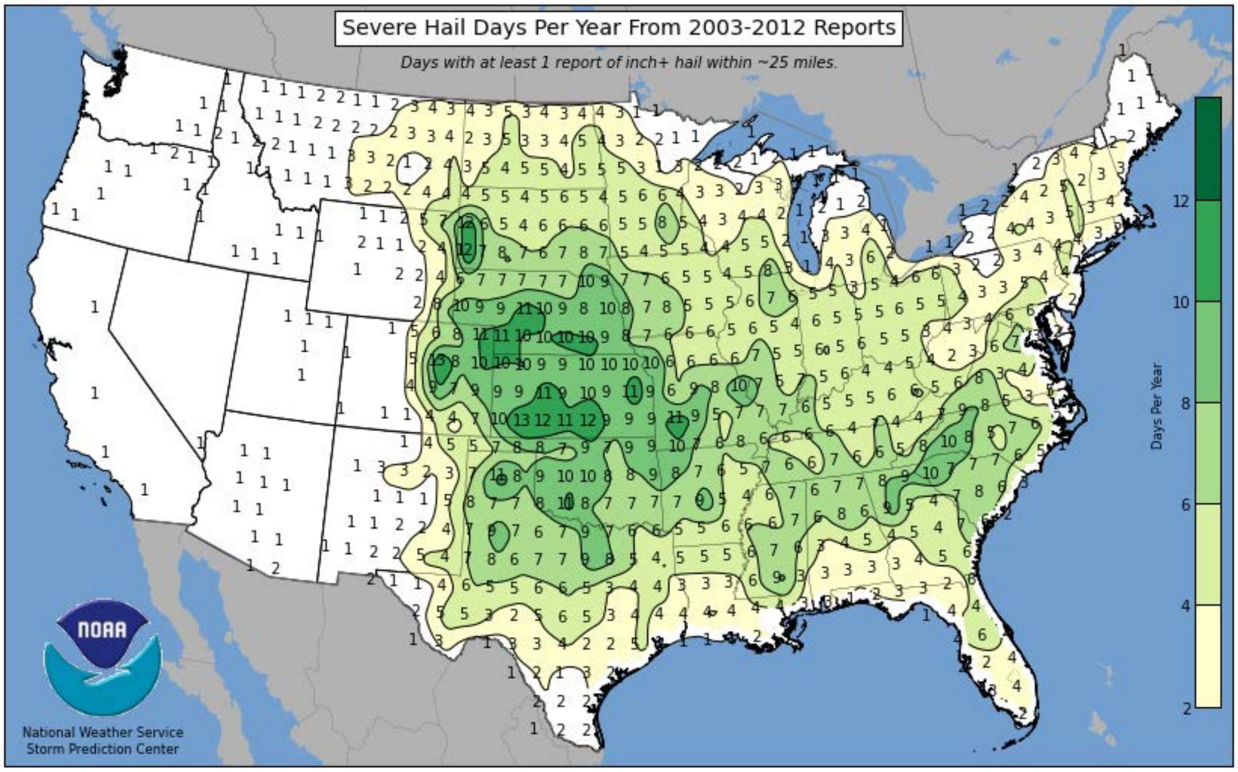


Figure 6. Severe hail days in the U.S.[36]

Figure 6 is a map of the U.S. produced by the National Weather Service Storm Prediction Center. It shows the number of severe hail days per year from 2003 to 2012. In Kentucky, the number of severe hail days ranges from 4 to 7, with higher frequencies in the western part of the state.

Severe hail can significantly damage vehicles, structures, crops, and livestock. In terms of transportation infrastructure, roadway signage and signalization are the most likely to suffer damage from hail. Severe hail can also temporarily disrupt the transportation system.

4.1.5. Winter Storms

Winter storms are a common occurrence in Kentucky. Winter storms can generate heavy snow, sleet, and freezing rain. Figure 7 shows the annual snowfall amounts received around Kentucky. Eastern Kentucky, defined by its mountainous terrain, experiences the highest annual snowfall, while the western and southern parts are characterized by low snowfall amounts.

[36] NOAA, "Storm Prediction Center Warning Coordination Meteorologist's Page."

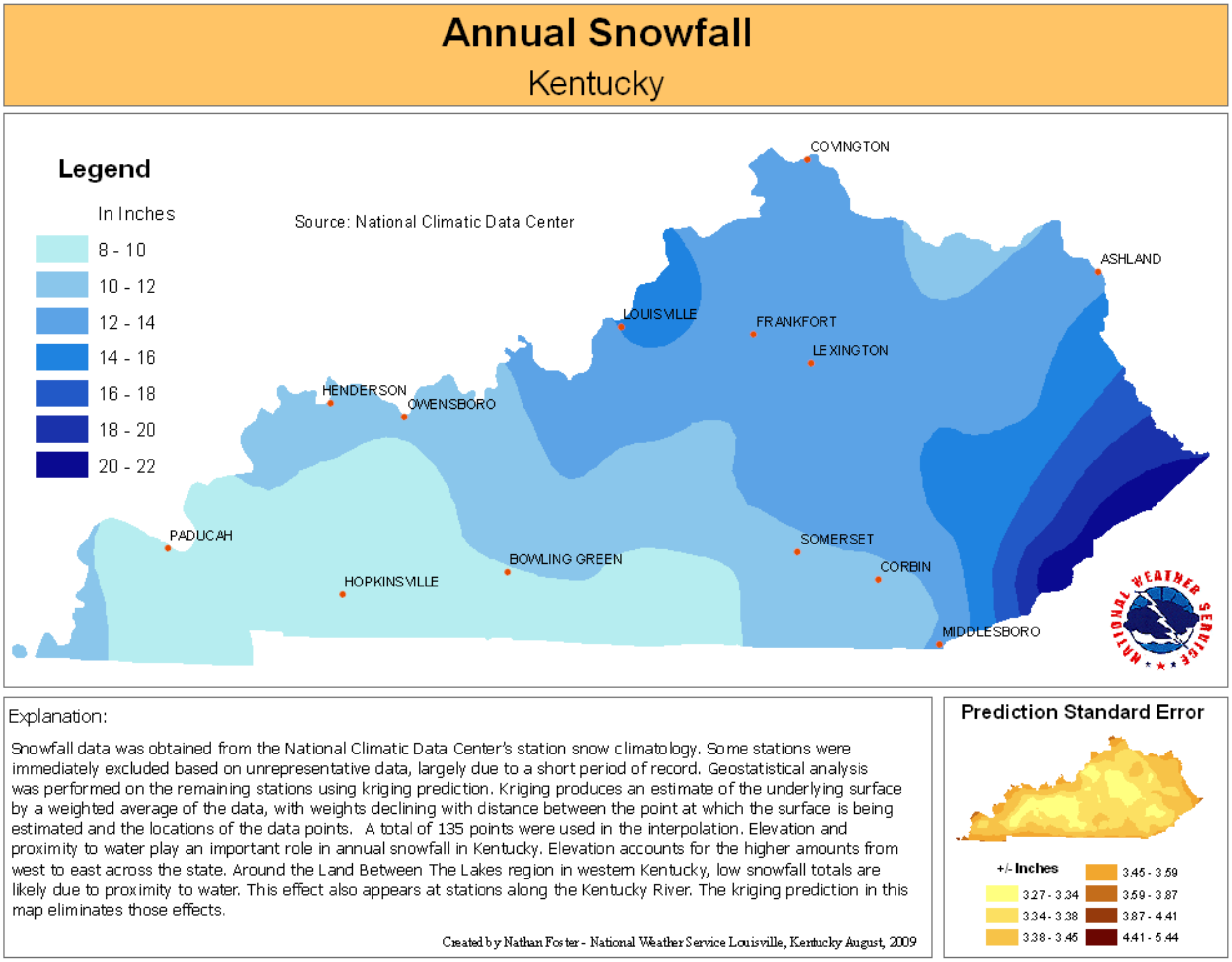


Figure 7. Annual snowfall in Kentucky.[37]

Winter storms introduce traffic safety problems and cause significant travel delays. As roadway conditions deteriorate, vehicle collisions and roadway departures become much more likely. When intense snowfall occurs, traffic on interstates may slow to a crawl or stop completely, stranding drivers in the cold until the roads are treated. Ice storms can down tree limbs and power lines, blocking roads and resulting in safety hazards. KYTC spends over $40 million each year on its snow and ice clearance program. Deicing salts produce deterioration on bridges and other structures.

4.1.6. Extreme Heat

The National Weather Service (NWS) defines extreme heat as temperatures 10˚F or more above the average summer high temperature. A heat advisory is issued when the forecast heat index is expected to be between 105˚F and 115˚F for *less than three hours* per day, or nighttime lows are forecast to be above 80˚F, for two consecutive days. Excessive Heat Warnings are issued when the heat index is forecast to exceed 105˚F for more than three hours on two consecutive

[37] Foster, "Kentucky Normal Annual Snowfall."

days, or if it is forecast to be above 115˚F for any period of time.[38] Chapter 5 examines some of the extreme heat historical trends and future projections for Kentucky.

Extreme temperatures, particularly extreme heat, can damage transportation infrastructure. Many factors contribute to the specific threshold at which extreme heat will impact pavement, including the pavement type, duration of heat exposure, and traffic conditions. 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. Additionally, excessive heat can place stress on steel bridge joints through thermal expansion.[39] Extreme heat and extreme cold can impede highway operations by limiting the availability of construction and maintenance activities.

4.1.7. Freeze Thaw

Freeze/thaw cycles refer to the change in the ambient air temperature, alternating between above and below the freezing point (32˚F). Freeze/thaw cycles can cause moisture to expand and contract, which can damage transportation infrastructure. Spatial and temporal patterns of freeze/thaw cycle occurrences in Kentucky are described in Chapter 5.

Freeze/thaw cycles are the primary natural cause of damage to highway pavements in areas where they occur most frequently.[40] When the air temperature dips below freezing, water that has seeped into cracks or voids in the pavement due to wear and tear freezes, expands, and exerts upward pressure on the pavement. When the air warms and the water melts, the ground returns to its normal size, but the pavement remains bubbled up. As cars travel over this bubble in the pavement, the road eventually gives way, resulting in a pothole.

4.1.8. Fog

Fog is most simply defined as a cloud at ground level. Fog consists of suspended water droplets at the Earth's surface which restrict visibility; it may persist for an extended period of time. Some of the variables used to define a fog event include the fog's intensity or 'thickness', color, duration, extent, and time of day. At highway speeds, fog is considered to be hazardous when visibility is reduced to around 600 feet or less. This hazard becomes more severe when visibility falls to 280 feet or less. Highways can be closed to traffic when visibility drops below 175 feet.[41]

Fog can occur throughout the United States, although it is more common in some areas than in others. Parts of New England, Central Appalachia, and the Pacific Northwest experience fog events most frequently. In Kentucky, fog events occur most often in the eastern part of the state. Moving westward, the average number of days with fog per year declines.

[38] National Weather Service, "Heat Watch vs. Warning."
[39] Meyer et al., "Volume 2: Climate Change, Extreme Weather Events, and the Highway System: Practitioner's Guide and Research Report"; TRB, "Potential Impacts of Climate Change on U.S. Transportation."
[40] Özgan et al., "Effects of Freezing and Thawing on the Consolidation Settlement of Soils."
[41] FHWA, "Best Practices for Road Weather Management."

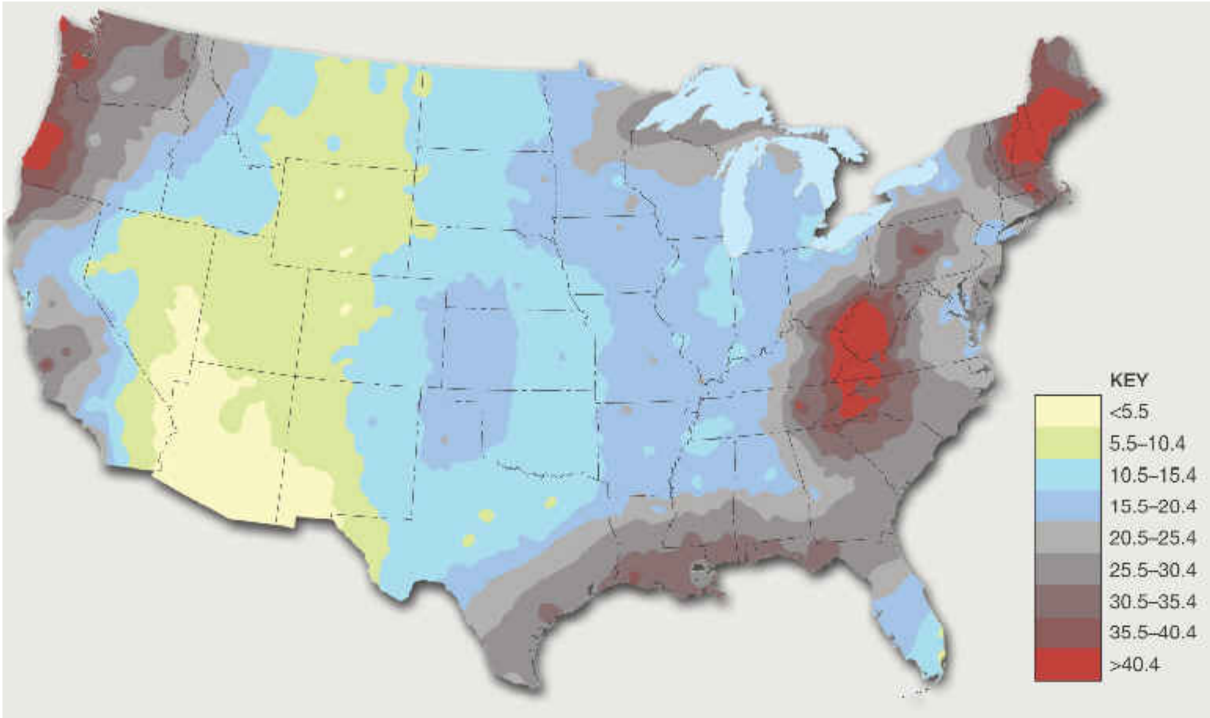


Figure 8. Average number of days per year with heavy fog.[42]

Although fog does not pose a significant hazard to transportation assets per se, it is a hazard that impairs the transportation system's operation, and can significantly influence traffic safety. Fog can trigger vehicular collisions and system delays. In the U.S., hundreds of fatal crashes occur annually due to fog, and the total number crashes each year which are attributable to fog is the tens of thousands.[43] From 2005-2014, 495 people were killed in the U.S. in fog-related crashes — 9 percent of weather-related highway fatalities over that period.[44] Reduced visibility from fog can also cause significant problems for air and marine transportation.

4.1.9. Drought/Wildfire

Drought impacts on the transportation system are rare but possible. Roads built in wetland areas are potentially most vulnerable to extremely dry conditions. In cases of extreme drought, wetlands can dry out, causing a change in soil composition, which may degrade the underlying roadbed. Instances of this occurring have been documented in states such as Louisiana.

Droughts sometimes lead to wildfires. Though wildfire is not strictly a meteorological hazard, it is included here because of its relation to precipitation, drought, and wind. There are three different types of wildfire:[45]

- Surface fires — These fires consume only surface material. As such, they are the least destructive and easiest to put out.

[42] El Dorado Weather, "Climate Atlas of the United States."
[43] Hamilton et al., "Hidden Highways: Fog and Traffic Crashes on America's Roads."
[44] FHWA, "How Do Weather Events Impact Roads?"
[45] NRCAN, "Fire Behaviour."

- Ground fires — These fires occur in accumulations of humus, peat, and similar dead vegetation. Although they move slowly, they can be difficult to put out.
- Crown fires — The most intense and dangerous wildfire, these consume trees entirely.

The majority of fires are attributable to lightning strikes or human activity. Such events are more likely to catalyze wildfires under conditions of infrequent rainfall or drought, elevated temperatures, and the accumulation of combustible material along a forest floor. Wind can also facilitate the spread of fire across the landscape.

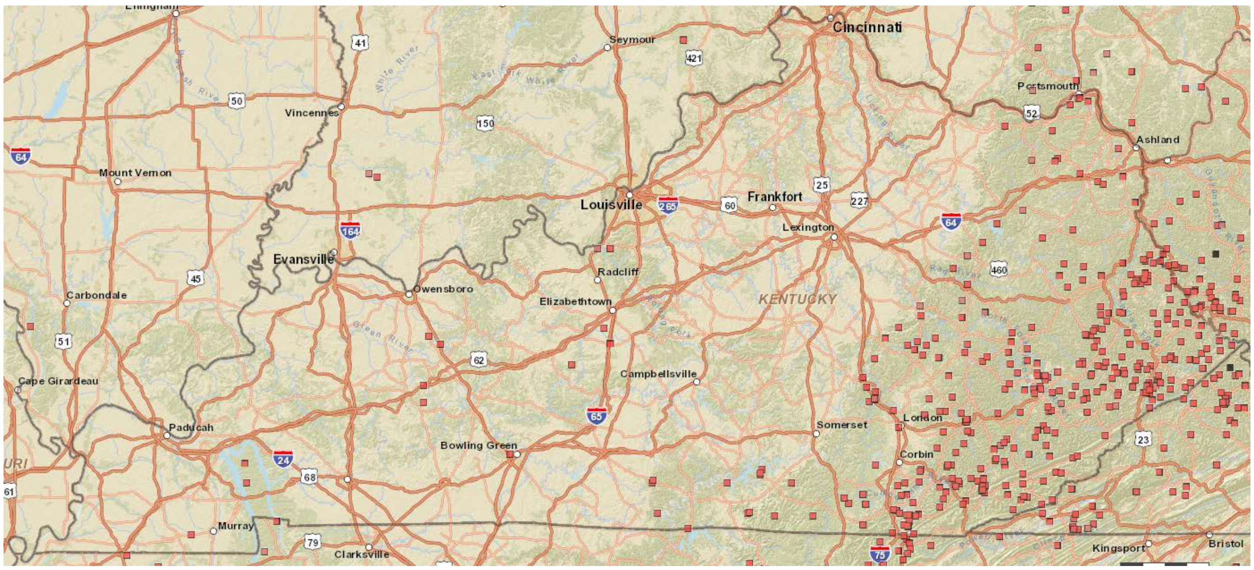


Figure 9. Map of all wildfires in Kentucky from 2010-2015.[46]

Wildfire impacts on the transportation system include system delays and costs associated with recovery. Costs may include maintenance and damage assessment, replacement or repair of roads, guardrails, signage, electrical supply, culverts, and landscaping.[47]

4.2. Geological

Kentucky's landforms follow a distinct east-west gradient. Elevations are highest and slopes steepest in the east, where the Appalachian Mountains and Plateaus represent approximately 25 percent of the state's area. The Bluegrass Region is located in the north-central part of the state; it is a flatter and agriculturally productive region. To the south and stretching westward is the Pennyroyal region, an area dense with karst landscapes. Adjacent to the Ohio River and encircled by the Pennyroyal is the Western Kentucky Coal Fields physiographic province. Farther west is the Jackson Purchase region, which is a northward extension of the Mississippi River embayment and Gulf Coastal Plain. Surface streams generally flow southeast to northwest in Kentucky, with the Licking River, Kentucky River, Green River, Cumberland River, and Tennessee River all being significant tributaries of the Ohio River.

Kentucky's physical geography accounts for several types of geologic hazards. Landslides and rock falls can occur throughout the state, but are most common in the eastern mountains and plateaus. Karst formations are common in the Pennyroyal and Bluegrass regions. Karst is

[46] USGS, "GeoMAC Wildland Fire Support."
[47] Diaz, "Economic Impacts of Wildfire."

especially conducive to sinkhole development. Western parts of the state are proximate to two seismic zones, the New Madrid seismic zone along the Mississippi River of Tennessee, Arkansas, Missouri, and Kentucky; and the less-active Wabash Valley seismic zone of Illinois, Indiana, and Kentucky.

4.2.1. Seismicity

An earthquake refers to a “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.”[48] 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 significantly different 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 3).

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.

[48] USGS, “Earthquake Glossary.”

Table 3. Comparison of Modified Mercalli Scale and Richter Scale.[49]

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 Strong	Sleepers awake; church bells ring	<25	<4.8	3.9-9.2
VI	Strong	Trees sway; suspended objects swing; objects fall off shelves	<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 damaged	<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	

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

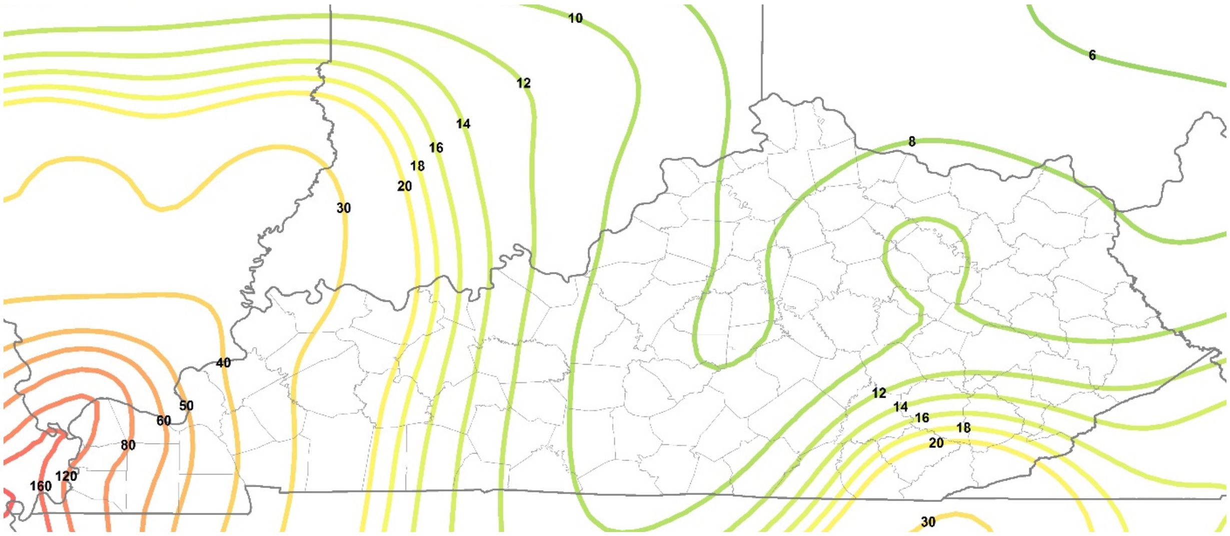


Figure 10. Peak ground acceleration with 2% probability of exceedance in 50 years. Peak acceleration expressed as a percent of gravity (%g).[50]

In the U.S., earthquakes are often intuitively associated with the west coast and the San Andreas seismic zone. That area is a part of the Pacific Ring of Fire, an area of the globe bordering the Pacific Ocean that is frequently subject to seismic activity and volcanic eruptions. In the eastern half of the U.S., the highest threat for seismic activity is along the New Madrid seismic zone, which runs along the Mississippi River in Tennessee, Arkansas, Kentucky, Illinois, and Missouri.

The most severe seismic activity ever recorded on the New Madrid seismic zone occurred in the winter of 1811-12, when a series of intense earthquakes of magnitude 7.0 or greater on the Richter scale occurred. Eyewitness accounts reported that the Mississippi River flowed backward, earth and sand being thrown in the air, structural damage (though the area was sparsely settled), and islands sinking into the river.[51] Shaking from the earthquakes was felt as far away as New Orleans; Charleston, South Carolina; and Toronto, Canada.[52] Reelfoot Lake, in northwestern Tennessee, also formed as a result of these earthquakes, as the Mississippi River channel was altered leaving water trapped in some areas while flowing in new and different areas. Since the early 1800s, only two significant earthquakes have occurred on the New Madrid seismic zone, an earthquake of magnitude 6.6 in 1895, and one of magnitude 5.4 in 1968.

Seismic hazard refers to the actual damage incurred from seismic activity through ground shaking, ground ruptures, induced landslides, and liquefaction.[53] Seismic risk refers to the likelihood of a seismic hazard occurring over a defined time period. Seismic risk is quantified by its probability, level of hazard (magnitude), and exposure time.[54] This is an important distinction to make for this vulnerability assessment. High-magnitude earthquakes, like those

[50] USGS, "PGA 2% in 50 Yrs."
[51] Johnston and Schweig, "The Enigma of the New Madrid Earthquakes of 1811-1812"; Nuttli, "Seismic Wave Attenuation and Magnitude Relations for Eastern North America."
[52] Orton, "Science and Public Policy of Earthquake Hazard Mitigation in the New Madrid Seismic Zone."
[53] Wang et al., "Seismic-Hazard Maps and Time Histories for the Commonwealth of Kentucky."
[54] Ibid.

which occurred in 1811-12, are expected to happen about every 500 to 1,000 years in the New Madrid seismic zone.[55] As such, given the expected lifecycles of transportation assets in western Kentucky, they are not likely to experience or be impacted by a severe earthquake. However, the chance does exist that they could.

4.2.2. Landslides

A landslide is defined as "the movement of a mass of rock, debris, or earth down a slope".[56] Landslide types can be divided into five categories to describe this movement:[57]

- Slides — refers to "mass movements where there is a distinct zone of weakness that separates the slide material from more stable underlying material" (USGS 2004)
- 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

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:[58]

- 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.[59]

[55] Ibid.
[56] Cruden, "A Simple Definition of a Landslide."
[57] USGS, "Landslide Types and Processes."
[58] Ibid.
[59] KGS, "Landslide Hazards in Kentucky."

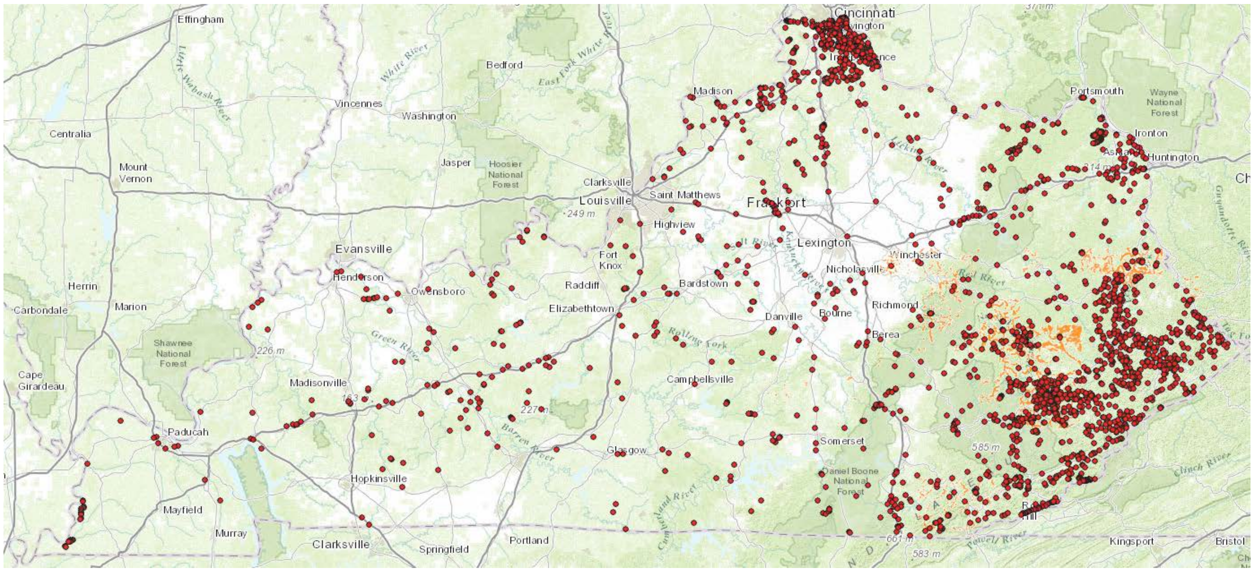


Figure 11. Documented landslides in Kentucky. Source: KGS Landslide Information Map.[60]

Landslides can damage transportation infrastructure, requiring considerable funds to repair. Lane closures required for the repair or clean up disrupts the transportation system. Safety is also a concern, roadway debris or cracks in the pavement can lead to crashes.

Table 4 summarizes the amount each KYTC district spent in fiscal year 2015 on maintenance related to landslides — in total, over $4 million each for Districts 6, 10, and 12, respectively. In general, expenditures were higher in eastern districts than in western ones. Total expenditures for the state exceeded $22 million.

Table 4. KYTC maintenance expenditures by district on all slides, FY 2015.

District	All Slides
1	$224,034
2	$648,088
3	$207,014
4	$830,352
5	$288,841
6	$4,864,571
7	$1,736,341
8	$427,568
9	$1,700,473
10	$4,239,911
11	$2,929,868
12	$4,638,121
ALL	$22,735,182

[60] KGS, "Landslide Information Map."

4.2.3. Sinkholes

Karst topography is "terrain with distinctive hydrology and landforms that arise from a combination of high rock solubility and well developed secondary (fracture) porosity".[61] 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.[62] 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.[63]

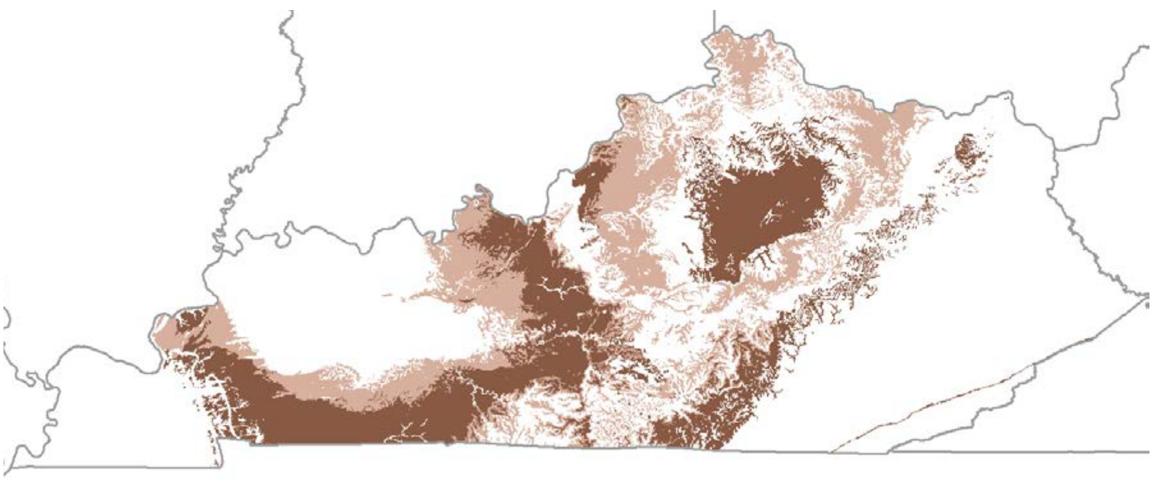


Figure 12: Karst potential in Kentucky.[64] The dark brown shading shows major karst areas of Kentucky; the light brown shows moderate karst areas.

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.[65] Karst-related flooding can cause temporary road closures, roadway damage, or problems with drainage and rainwater runoff.

[61] Ford and Williams, *Karst Hydrogeology and Geomorphology*.
[62] KYEM, "Commonwealth of Kentucky Enhanced Hazard Mitigation Plan."
[63] Currens, "Kentucky Is Karst Country! What You Should Know about Sinkholes and Springs."
[64] Paylor and Currens, "Karst Occurrence in Kentucky."
[65] Moore and Beck, "Karst Terrane and Transportation Issues."

5. Historical Geological and Meteorological Event Records

5.1. Historical Climate

FHWA guidance recommends using historical climate records for vulnerability assessments. Officials can use these records to better understand and communicate impacts associated with projected climate changes. Applications of historical climate records include:[66]

- Providing information on the transportation system's sensitivity to weather events.
- Understanding how the transportation system has responded to extreme temperature, precipitation, and wind events.
- Gauging the variability in weather conditions. This helps provide context for projected climate change.
- Examining case studies of extreme weather events to raise awareness of vulnerabilities to various types of events.

To better understand historical trends of extreme weather events in Kentucky, the project team obtained data from the Midwestern Regional Climate Center (MRCC). Thresholds were identified by the project team to mark extreme occurrences of weather phenomena, such as extreme temperature, extreme precipitation, and extreme wind.

5.1.1. Historical Precipitation Data

County-level precipitation data for 1981-2015 were obtained from MRCC. The data show the number times that precipitation thresholds were exceeded based on grid points averaged at the county level. The thresholds for extreme precipitation were:

- Daily precipitation > 3"
- Daily precipitation > 7"
- Daily precipitation > 10"

Of these, there were few records of daily precipitation exceeding 7" or 10". The results for daily precipitation exceeding 3" are discussed below.

Figure 13 depicts the average number of days each year with 3 or more inches of rainfall. Counties in the far-western portion of the state, on average, experience rainfall events of this magnitude once every 2.5 years or less. These events are more infrequent in the easternmost portion of the state — occurring on average once every 10 years or more. There is an evident west-to-east gradient, with counties located in the western part of the state (west of I-65) much more likely to experience heavy rainfall events.

[66] "The Use of Climate Information in Vulnerability Assessments."

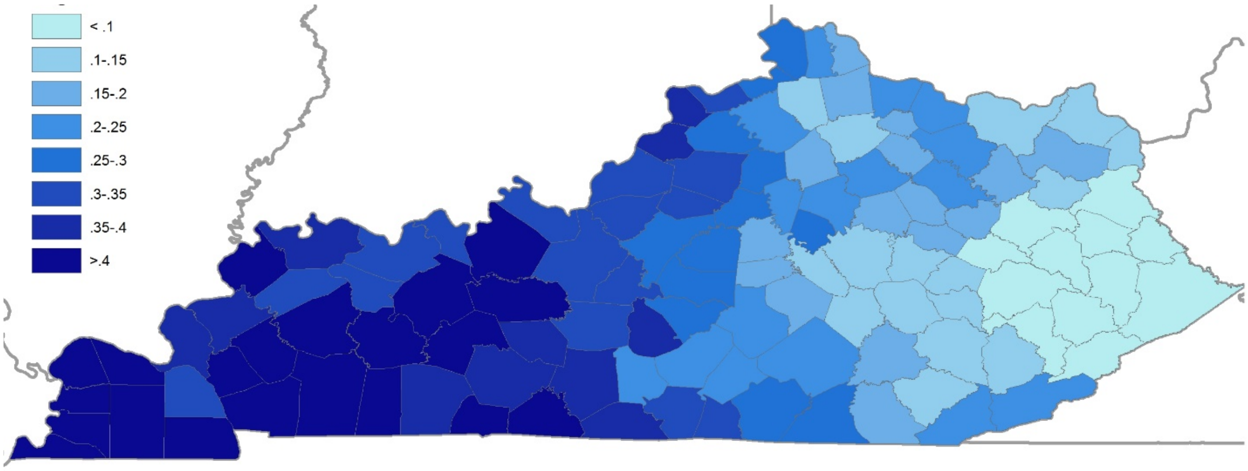


Figure 13. Average annual number of days with 3 or more inches of rainfall; 1981-2015.

Looking at the occurrences of heavy rainfall events of 3 inches or more reveals considerable temporal variability. From 2006 to 2010, there were more heavy rainfall events — particularly for the KYTC districts in western Kentucky — than during any other 5-year period over this span, with a statewide average of an event taking place nearly every other year (.457). The years of 1991-95 had the fewest occurrences of heavy rainfall, with a statewide average of one event less than every 10 years (.078). Across all KYTC districts, heavy rainfall events have occurred with slightly greater frequency over time, but because of the significant variation and shortness of the study period, conclusive findings are not possible.

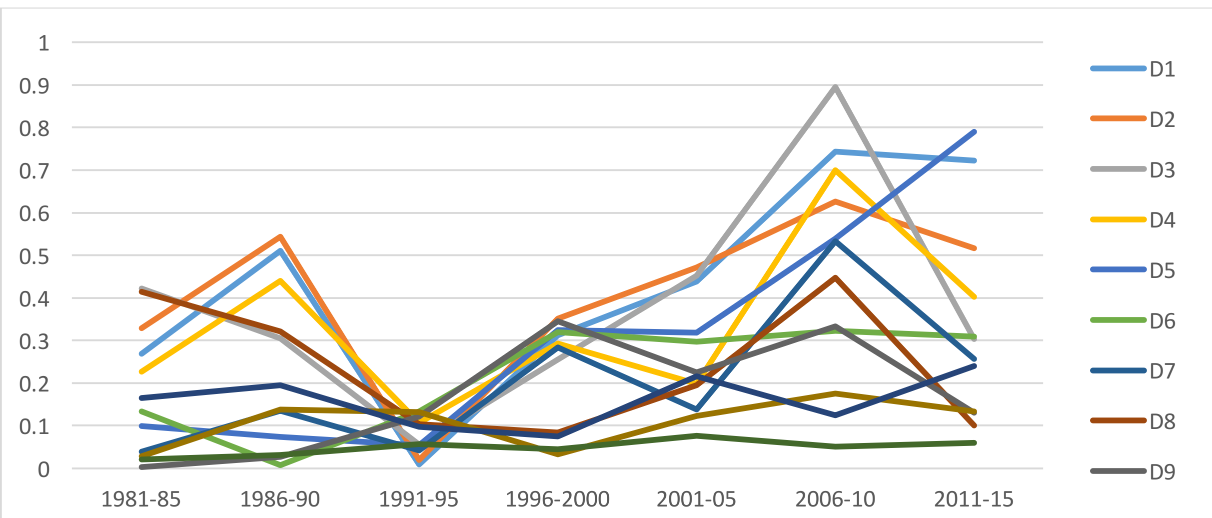


Figure 14. Average annual number of days with 3: or more rainfall per KYTC district; 1981-2015.

5.1.2. Historical Temperature Data

County-level temperature data for 1981-2015 were also obtained from MRCC. The data show the number of occurrences per grid point averaged at the county level where temperature thresholds were exceeded. The thresholds for extreme temperature are:

- Maximum temperature > 105°F
- Maximum temperature > 95°F
- Minimum daily temperature > 90°F

- Minimum daily temperature > 80°F

There were few instances of the maximum temperature exceeding 105°F or the minimum daily temperature topping 80°F. The results for maximum temperature exceeding 95°F are discussed below.

The spatial pattern of extreme temperature events is similar to the pattern found in the precipitation data. Western parts of the state have experienced far more days where the maximum temperature exceeded 95°F than eastern portions of the state, with I-65 roughly marking the cutoff point between the two.

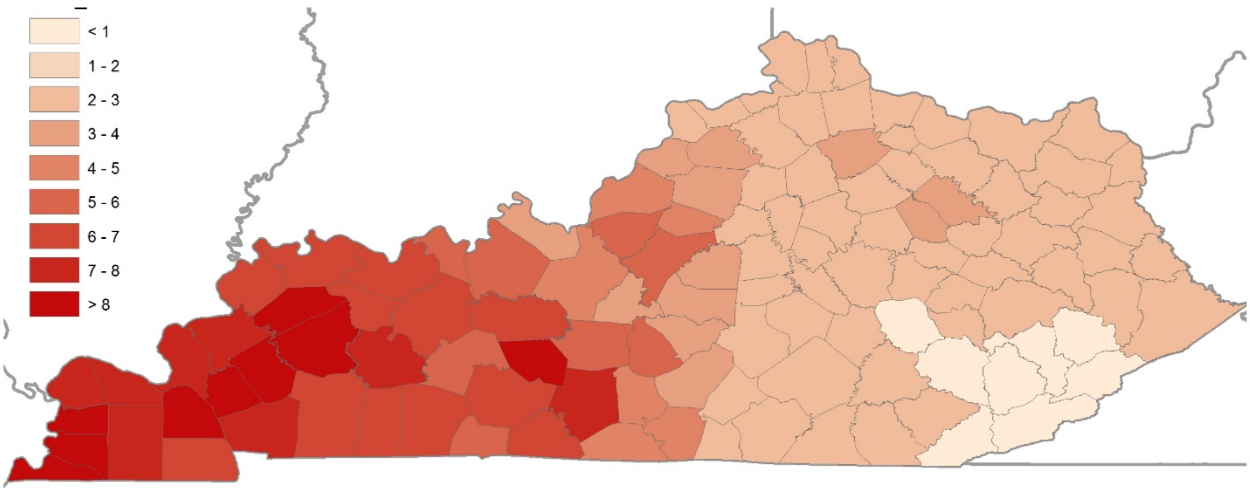


Figure 15. Average annual number of days where the maximum air temperature exceeds 95 degrees Fahrenheit; 1981-2015.

The 5-year averages also reveals considerable temporal variability. The 5-year period with the extreme heat events was 1986-90, with a statewide average of over 6 days per year. The 5-year period with fewest high heat days was 2001-05, with a statewide average of just over two such days per year. As with the precipitation data, the study period is too short to suggest conclusive findings about the future likelihood of extreme heat days.

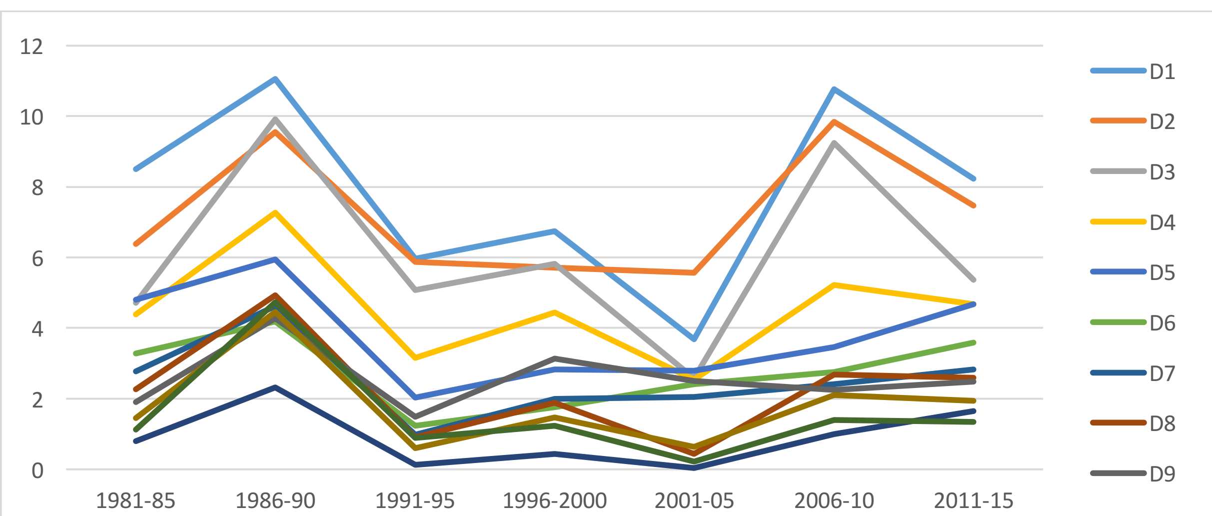


Figure 16. Annual average number of days where the maximum temperature exceeds 95 F; 1981-2015.

5.1.3. Historical Freeze/Thaw Days

Freeze/thaw days are defined as 24-hour periods where the maximum ambient temperature exceeds the freezing point of water (32°F) while the minimum ambient temperature drops below this point. MRCC calculated the number of freeze/thaw days by counting the number of days per grid point where these temperature criteria were met and then averaging the count across each county for each year from 1981-2015.

As with extreme precipitation and temperature data, freeze/thaw data have a spatial gradient, although there is more interregional variability. Eastern Kentucky experiences many more freeze/thaw days than western Kentucky. Some counties in the eastern portion of the state, such as Carter and Lawrence, experience on average up to 105 such days a year, while some western counties, such as Calloway and Graves, can have as few as 67 such days. Urbanized counties, such as Jefferson, Fayette, and Kenton, experience fewer freeze/thaw days than surrounding counties due to the urban heat island effect. A pocket of central-western counties centered on Grayson County also experience more freeze/thaw days, deviating from the overall west-east pattern.

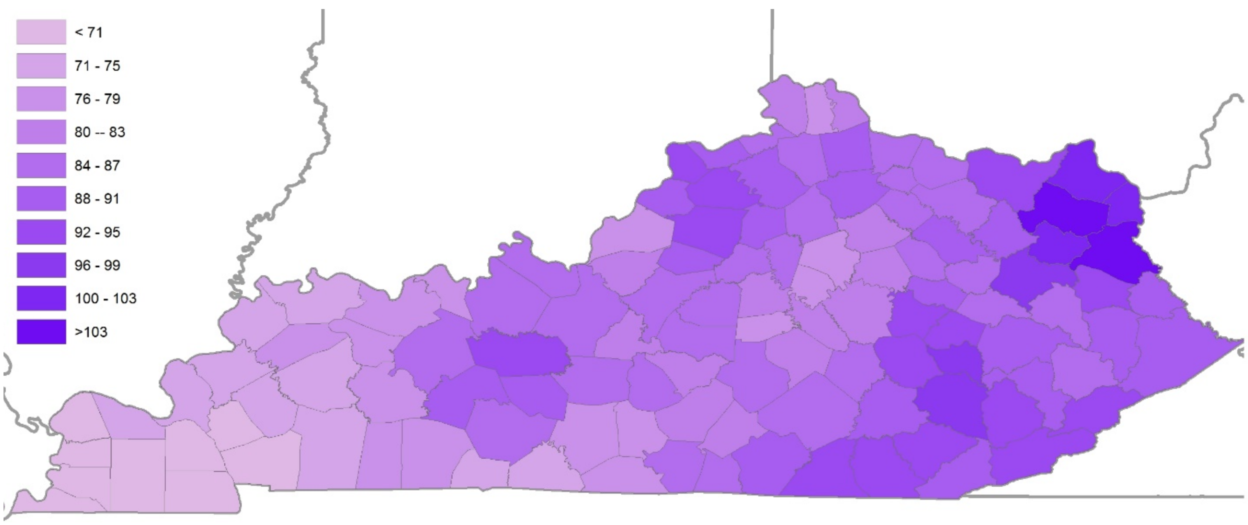


Figure 17. Average annual number of freeze/thaw days; 1981-2015.

The average annual number of freeze/thaw days has shown greater temporal consistency than extreme precipitation and temperature data. The 5-year period where the statewide annual average was highest was 1986-90, while the period with the lowest average was 2006-10. The overall trend does seem to indicate slightly fewer freeze/thaw days over time (2.8 fewer freeze/thaw days across the state over this time period).

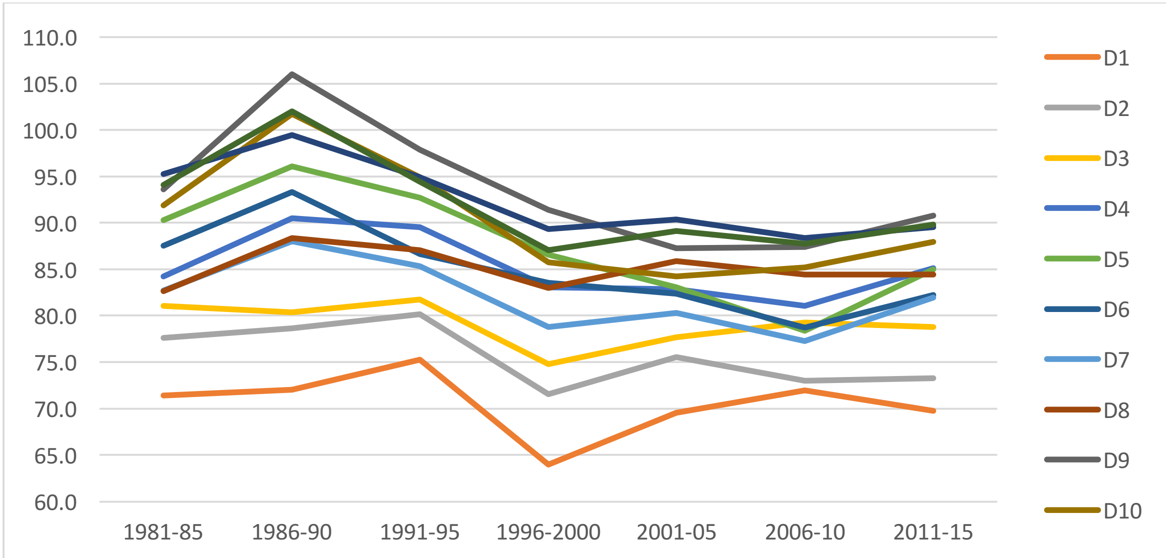


Figure 18. Average annual number of freeze/thaw days per KYTC district; 1981-2015.

5.1.4. Historical High Wind Events

Data for extreme wind events were also obtained from MRCC for 1981-2015. This dataset does not include observations from every county in the state — only from 10 weather stations distributed across the state. High wind events can be very local phenomena, so these data should be interpreted as a snapshot of historical weather at these points, rather than as an exhaustive picture of the likelihood of high wind events across the state.

The thresholds for high wind events were:

- Wind speed > 65 mph
- Wind speed > 75 mph

The map below shows the number of high wind events (> 65 mph) for each station.

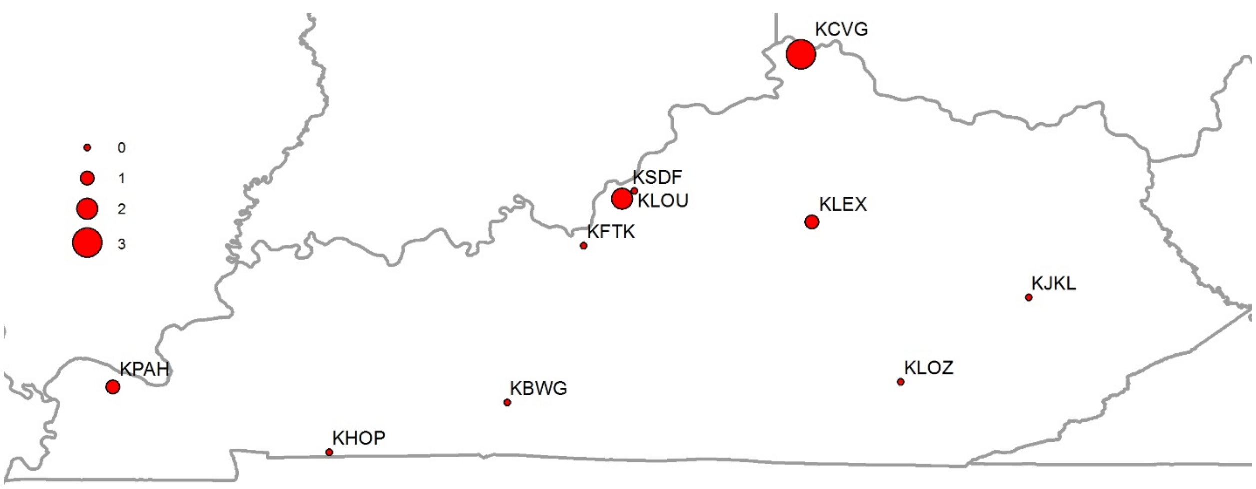


Figure 19. Number of high wind events recorded per station from 1981-2015.

5.1.5. Seasonal Variation in Historical Climate Trends

Statewide climate trends can also be observed for historical temperature and precipitation data at both the annual and seasonal level. The following data for the years 1895 to 2015 were provided by Dr. Stuart Foster, the Kentucky State Climatologist and Director of the Kentucky Climate Center at Western Kentucky University.

Figure 20 depicts annual climate trends in terms of mean temperature and total precipitation in Kentucky from 1895 to 2015. The observed values vary considerably from year to year, while the smoothing lines reveal the trends. The temperature trends show that Kentucky has warmed since the 1970s, but the recent warming is about the same as what occurred during the 1930s. Precipitation trends reveal a slow and steady increase in annual precipitation of several inches over the time period.

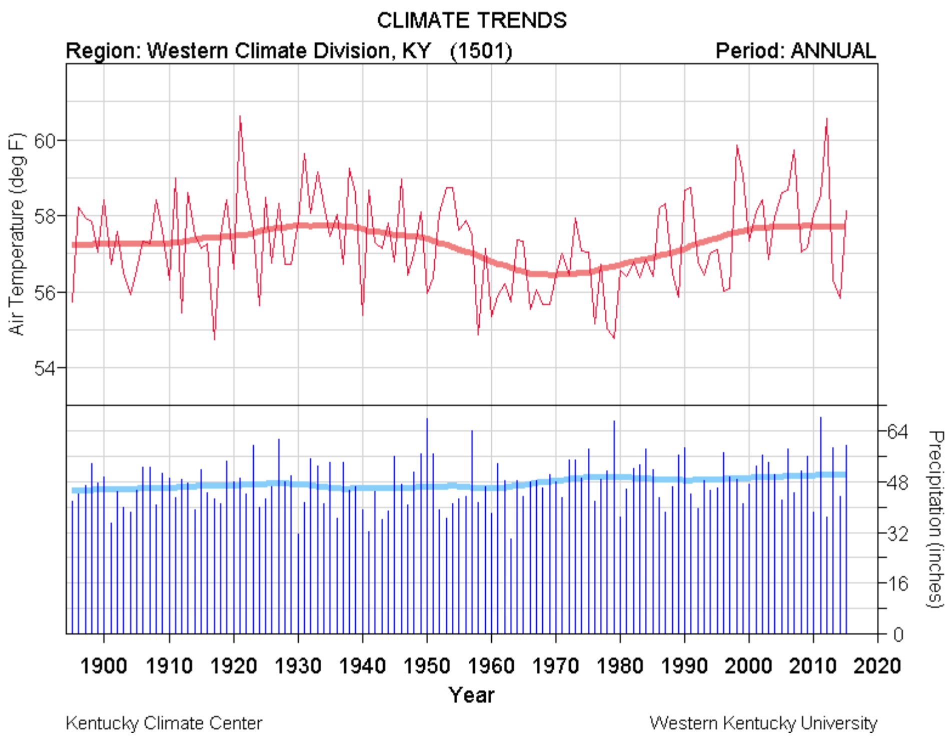


Figure 20. Annual trends in temperature and precipitation for Kentucky, 1895-2015.[67]

Figure 21 shows the seasonal variation in mean temperature and total precipitation in Kentucky between 1895 and 2015. From 2000 to 2015 winter temperatures cooled, while spring and summer temperatures warmed slightly and fall temperatures remained unchanged. Similarly, from 2000 to 2015 average precipitation totals in winter declined, while precipitation increased during the other three seasons.

[67] Foster, "Climate Trends."

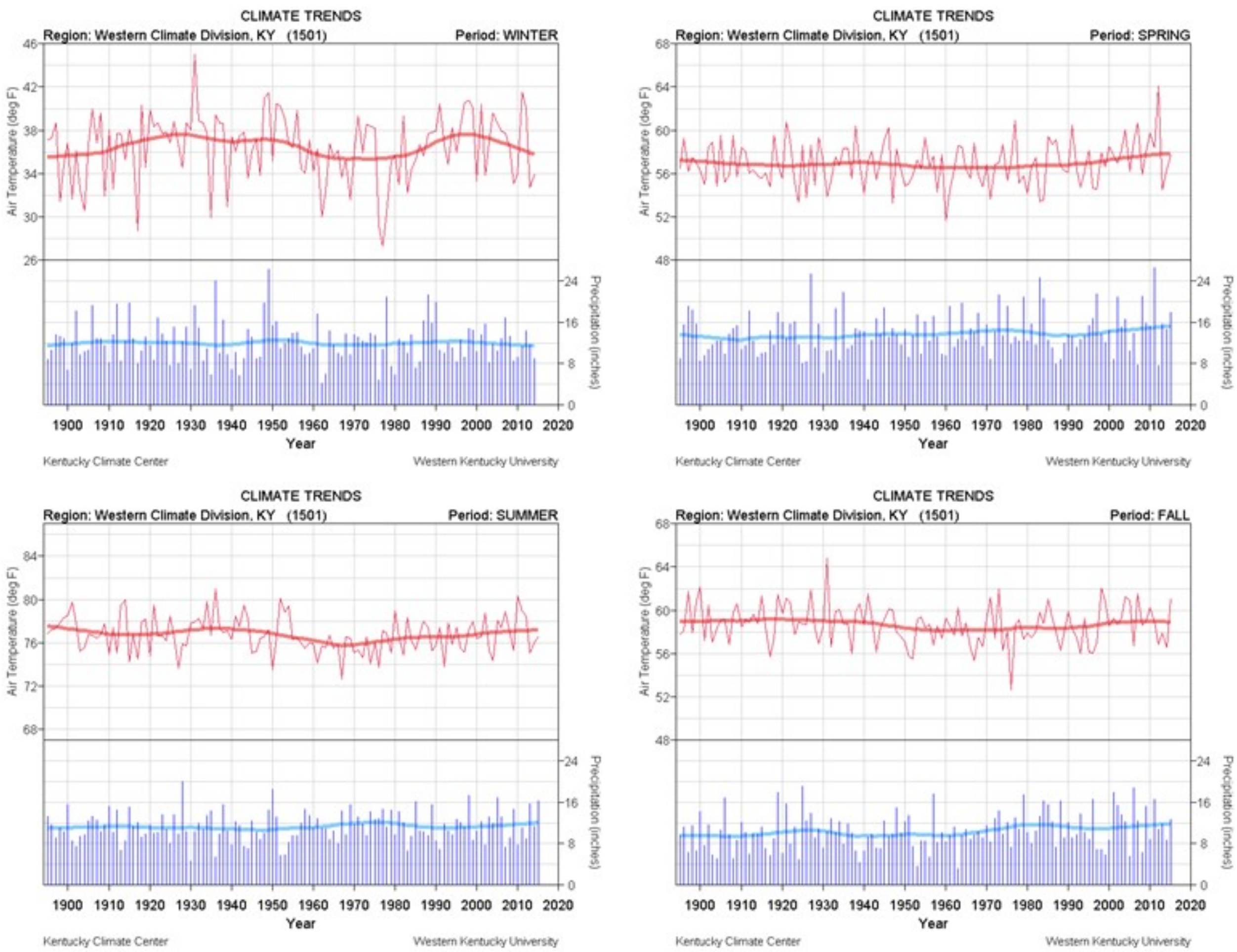


Figure 21. Seasonal variation in annual climate trends in Kentucky, 1895-2015.[68]

5.2. Climate Change

5.2.1. Introduction and Background

In the scientific community, there is widespread acceptance of human-caused climate change. Surveys of the scientific community have shown that 97 percent of active climate scientists in the U.S. accept this viewpoint.[69] While the global climate is always in flux, the rapid rate of warming that is occurring is unprecedented. Projecting the magnitude of climate change is an exceptionally complex task, and understanding the potential impacts of climate change across different areas of the world is an ongoing endeavor. Some areas — particularly higher latitude regions — are currently experiencing immediate impacts as a result of global climate change. In other parts of the world, such as Kentucky, climatic impacts are projected to be more gradual.

In 2008, a meeting was held by the World Climate Research Program that brought twenty climate modeling groups together from around the world to discuss and make recommendations regarding future climate models. One of the main outcomes of that meeting was the recommendation of conducting coordinated climate model experiments. These

[68] Ibid.

[69] Doran and Zimmerman, "Examining the Scientific Consensus on Climate Change"; Anderegg et al., "Expert Credibility in Climate Change."

experiments have since been conducted as part of the Coupled Model Intercomparison Project (CMIP), the most recent phase of which (CMIP5) was completed in 2014. The CMIP5 helped provide guidance regarding uncertainty with future global climate models (GCMs). CMIP5 outputs specifically provided context to the mechanisms of poorly understood details regarding the feedback between the carbon cycle and clouds in the atmosphere. CMIP5 also examined climate predictability and examined the ability of models to predict climate on two time scales, near term to 2035, and long term, 2035-2100. Finally CMIP5 helped determine why similarly forced models were producing a varied range of responses.

5.2.2. National Climate Development and Advisory Committee

The National Climate Development and Advisory Committee (NCADAC) is a federal advisory committee tasked with producing a national assessment of climate change every four years. The 2013 assessment included climate change projections at the regional level. Kentucky is part of the Southeastern region.[70]

Climate modeling often examines different greenhouse gas (GHG) emissions scenarios. Under high GHG emissions scenarios, the level of emissions continue to increase unabated, while low emission scenarios assume GHG emissions will decline.

Table 5 presents annual and seasonal temperature projections for the southeastern United States from 2021-2050, 2041-2070, and 2070-2099. The reference period is 1971-1999.[71] The value ranges are from high (A2) and low (B1) emissions scenarios. Annual mean temperatures are forecast to increase under all scenarios.

Table 5. Distribution of the simulated change in annual mean temperature (°F) from the B1 and A2 CMIP2 models for the Southeast region, with respect to the reference period of 1971-1999.[72]

Southeast (Temperature)		**2021-2050 (°F)**	**2041-2070 (°F)**	**2070-2099 (°F)**
A2 (high emissions scenario)	Lowest	1.3	2.3	3.9
	25th Percentile	2.2	3.8	6.5
	Median	2.8	4.4	6.8
	75th Percentile	3.1	4.6	8.0
	Highest	3.6	5.4	9.6
B1 (low emissions scenario)	Lowest	1.3	1.6	2.8
	25th Percentile	2.1	2.8	3.6
	Median	2.3	3.1	4.1
	75th Percentile	2.5	3.3	4.5

70 Kunkel et al., "Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 2. Climate of the Southeast U.S."
71 Ibid.
72 Ibid.

	Highest	3.2	3.8	5.2

Figure 22 shows the simulated change in the annual number of days where the maximum temperature exceeds 95°F. Models project that more extreme temperatures will impact all of Kentucky, although western parts of the state will be more affected than central and eastern portions of the state. Figure 22 illustrates the simulated change in the annual number of days on which the minimum temperature falls below 32°F. All areas of Kentucky are projected to have significantly fewer days where the temperature is below freezing.

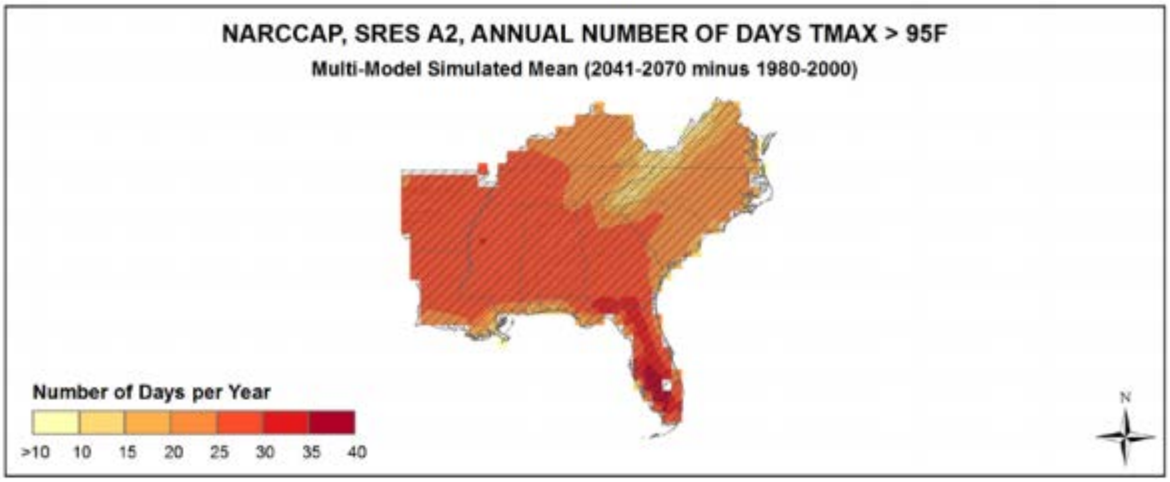


Figure 22. Simulated difference in the mean annual number of days with a maximum temperature greater than 95°F for the Southeast region for the 2041-2070 time period with respect to the reference period of 1920-2000.[73]

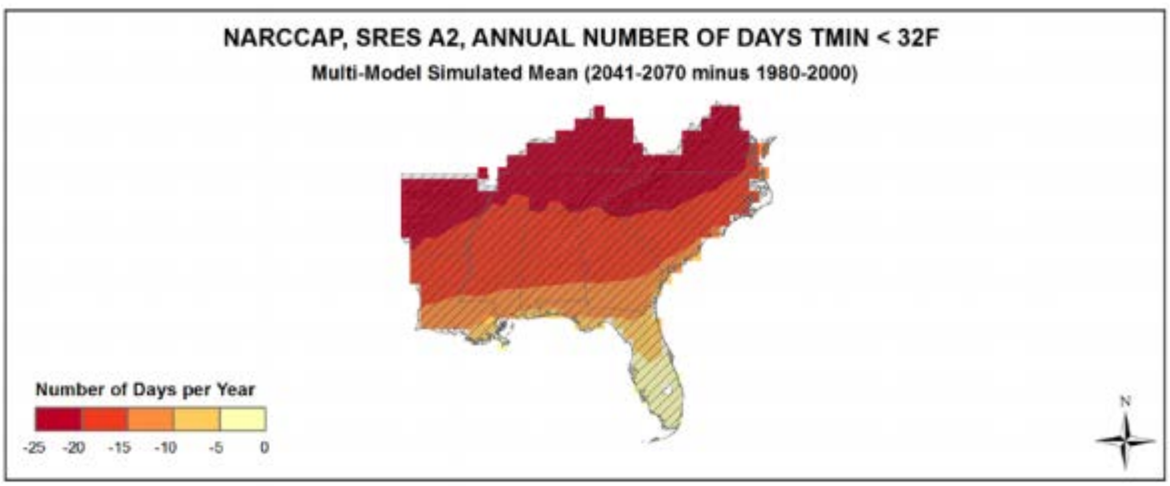


Figure 23. Simulated difference in the mean annual number of days with a minimum temperature lower than 32°F for the Southeast region for the 2041-2070 time period with respect to the reference period of 1920-2000.[74]

[73] Ibid.
[74] Ibid.

Table 6 presents modeled changes in precipitation for the southeastern United States from 2021-2050, 2041-2070, and 2070-2099.[75] The table includes a range of emissions scenarios, from high (A2) and low (B1). Projections show a wide range of change in precipitation, from greatly reduced annual means to significantly higher annual means. Median projections for both scenarios result in a moderate increase in annual mean precipitation.

Table 6. Distribution of the simulated change in annual mean precipitation (%) from the B1 and A2 CMIP3 models for the Southeast region, with respect to the reference period of 1971-1999.[76]

Southeast (Precipitation)		**2021-2050 (°F)**	**2041-2070 (°F)**	**2070-2099 (°F)**
A2 (high emissions scenario)	Lowest	-9	-14	-23
	25th Percentile	-2	-6	-12
	Median	2	2	4
	75th Percentile	3	4	6
	Highest	8	8	11
B1 (low emissions scenario)	Lowest	-9	-11	-12
	25th Percentile	-1	-1	-1
	Median	1	3	4
	75th Percentile	3	4	5
	Highest	5	7	9

Projected changes in seasonal variability are uneven, with winters projected to be considerably wetter and summers projected to be considerably drier (Figure 22). Figure 23 shows the change in the annual number of days on which one inch or more of precipitation falls. All of Kentucky shows a greater percentage of days with high precipitation totals, with central and northern parts of the state most affected.

[75] United States Global Change Research Program, *Global Climate Change Impacts in the United States.*

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

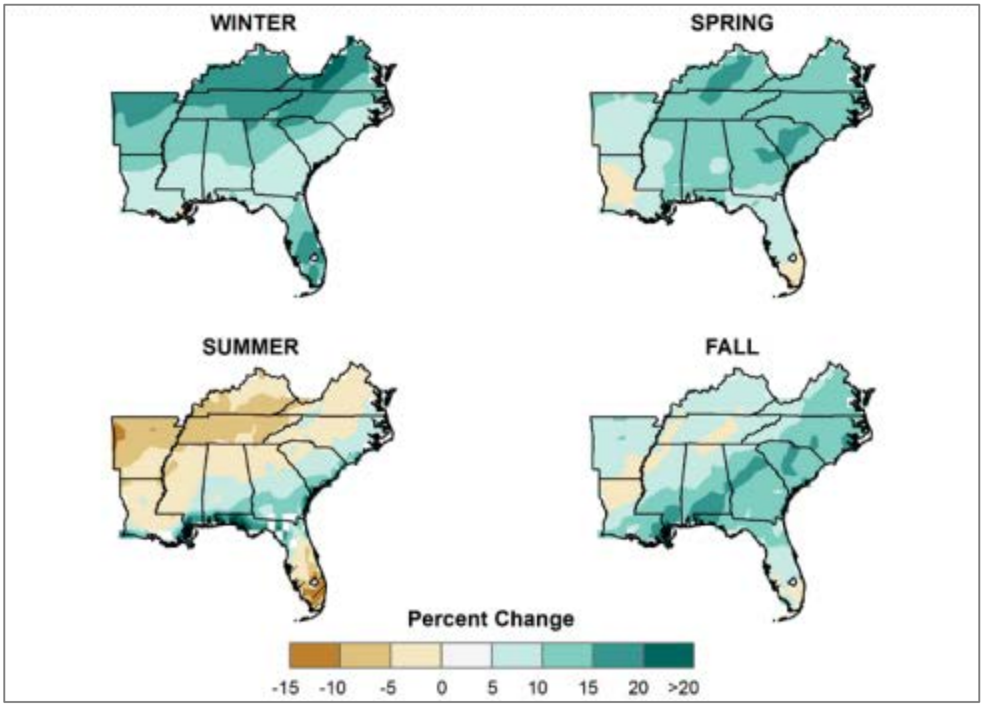


Figure 24. Simulated difference in annual and seasonal mean precipitation for the Southeast region for 2041-2070 with respect to the reference period of 1971-2000.[77]

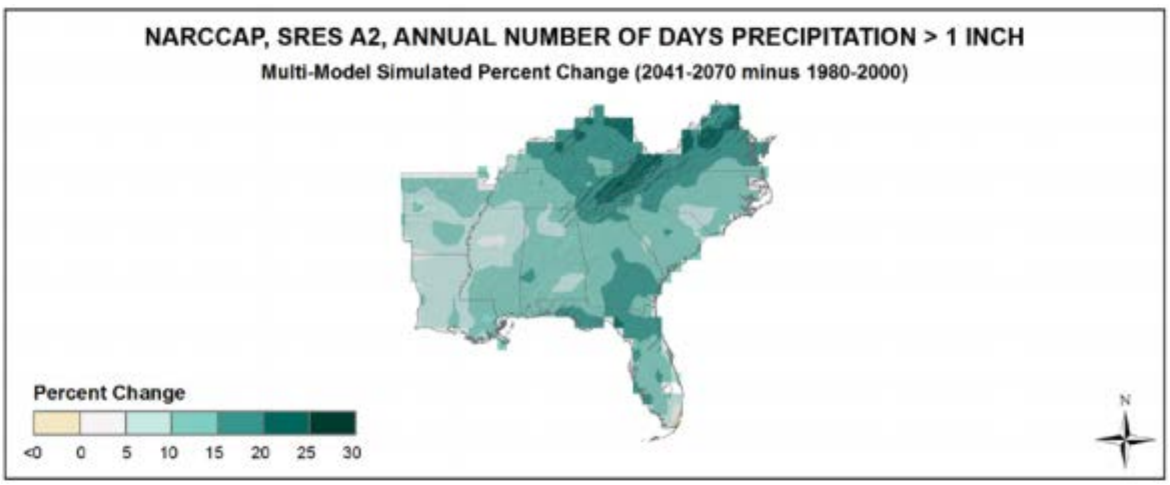


Figure 25. Simulated percentage difference in the mean annual number of days with precipitation of greater than one inch for the Southeast region for the 2041-2070 time period with reference period of 1980-2000.[78]

5.2.3. Oak Ridge National Laboratory Climate Change Science Institute

In October 2015, KYTC and KTC personnel met with representatives of Oak Ridge National Laboratory (ORNL) Climate Change Science Institute. At that meeting, ORNL scientists presented their research on downscaling historical and future climate data. These data were generated using ORNL's Titan supercomputer. Historical and future climate simulations were produced using the dynamical downscaling of the GCMs from CMIP5. The GCMs used in CMIP5

[77] Ibid.
[78] Ibid.

were central in the development of the 2013 Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report. For historical baseline values, ORNL downscaled 11 GCMs and generated data that derived an average of those 11 GCM ensembles. These simulations covered the historical period from 1965 to 2005.

The following CMIP5 GCMs were used for baseline and future dynamical downscaling simulations:

- Australian Community Climate and Earth System Simulator Model (ACCESS1-0)
- Beijing Climate Center Climate model (BCC-CSM)
- Community Climate System Model (CCSM4)
- Centro Euro-Mediterraneo sui Cambiamenti Climatici Climate Model (CMCC-CM)
- Chinese Academy of Sciences Model (FGOALS-g2)
- Geophysical Fluid Dynamics Laboratory-Earth System Model (GFDL-ESM2M)
- Institute Pierre Simon Laplace Climate Model 5 running on low resolution grid (IPSL-CM5A-LR)
- Model for Interdisciplinary Research on Climate 5 (MIROC5)
- Max-Planck-Institute Earth System Model running on medium resolution grid (MPI-ESM-MR)
- Meteorological Research Institute Coupled ocean-atmosphere General Circulation Model (MRI-CGCM3)
- Norwegian Earth System Model (NorESM1-M)

Downscaled versions of these GCMs were based on a regional climate model RegCM4. Data provided by ORNL created an ensemble that averaged of all these 11 downscaled GCMs and used a Representative Concentration Pathway 8.5 (RCP8.5) when calculating the future projections.[79]

ORNL provided KYTC with downscaled historical and future climatic modeling data on 4 km scale gridded area for the Commonwealth of Kentucky. A review of these data revealed future trends in climate. For the 2016–2050 period, the models suggest that maximum temperatures for the state will increase slightly. For high temperatures, the greatest increased value was predicted for 2050, with a cumulative increase for the 36j5 days of 14.91° C or 58.83° F. This would entail a 4.90° F average monthly increase or a 0.16° F daily increase. The climate models also indicate that total annual precipitation will increase slightly throughout the state. The greatest increase in precipitation is forecast to occur in 2017, with a cumulative annual increase of 16.34 mm or 0.64 inches. This equates to a 0.05-inch monthly increase or a daily average increase of 0.001 inches.

[79] Ashfaq et al., "High-Resolution Ensemble Projections of near-Term Regional Climate over the Continental U.S."; Ashfaq et al., "Near-Term Acceleration of Hydroclimatic Change in the Western U.S."; Ashfaq et al., "Influence of Climate Model Biases and Daily-Scale Temperature and Precipitation Events on Hydrological Impacts Assessment."

5.3. Implications for the Transportation System in Kentucky

There is considerable uncertainty associated with future climate projections. As 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.

Climate models suggest that Kentucky will gradually warm during the 21st century. Extremely hot summer days are more likely to occur while winters will grow milder. Impacts from these predicted climate changes could have varying effects to KYTC infrastructure. Higher maximum temperatures during the summer could result in prolonged periods of extreme heat and extended periods of drought. This could cause negative impacts to KYTC assets, such as increased incidents in pavement buckling from extreme heat events or an increase of soil subsidence-affected road bases from prolonged drought. Mitigation efforts may want to focus on these possibilities. On the other hand, fewer days where the temperature falls below 32°F means fewer freeze/thaw cycles and the accompanying association with pothole formation.

At the same time, Kentucky is likely to become wetter on average, with the winter and spring being considerably wetter while the summer season will be drier. Additionally, the projections show greater likelihood of heavy precipitation events. These projected trends would result in more frequent and severe flooding, while increasing the likelihood of extreme heat events and drought during the summer months. One of the major findings of this vulnerability assessment was that flooding, both flash flooding and river flooding, already cause significant impacts to KYTC assets. The projected increases in precipitation should be taken seriously and should be considered during the planning and design phases of future KYTC projects. This should be specifically emphasized, especially in the light of recent severe flooding events in southern West Virginia[80] and central Maryland[81] that resulted in severe societal impacts as well as major damage to transportation infrastructure.

[80] DiLiberto, "'Thousand-Year' Downpour Led to Deadly West Virginia Floods."
[81] National Weather Service, "Ellicott City Historic Rain and Flash Flood - July 30, 2016."

6. Hazards Survey and Results

In fall 2015, the project team administered a survey to assess perceptions of risk and vulnerability of the transportation system. The survey was conducted online, and was sent out to 50 KYTC Central Office and District personnel. 25 surveys were completed, resulting in a survey completion percentage of 50 percent.

The majority of survey respondents (13) were from KYTC's Central Office, while the remaining 12 respondents represented 8 of the 12 KYTC District Offices (all but Districts 8, 10, 11, and 12). Nearly half (12) of the respondents identified their division or area of expertise as Highway Design. Another six said their expertise was in Environmental Analysis, and the remainder were experts in Administration, Maintenance, Planning, or Other.

Survey participants were asked to evaluate a list of natural hazards for how significant their impacts are to Kentucky's transportation system. For each hazard, participants indicated the short-term impacts, long-term impacts, overall impacts, and probability of impacts on a scale of 1-5, with 1 being the lowest and 5 the highest. The results are summarized in Table 7.

Table 7. Results of KYTC survey on perceptions of hazards.

Hazard	Short-Term	Long-Term	Overall	Probability
Flood	3.57	3.18	3.45	3.52
Flash Flood	3.96	3.00	3.32	3.62
Snow/Ice	3.73	2.59	2.86	3.52
Wind	2.09	1.82	1.77	1.95
Freeze/Thaw	2.52	2.91	2.50	3.00
Tornado	2.96	2.33	2.59	2.57
Fog	2.17	1.45	1.50	1.67
Drought	1.50	1.95	1.86	1.75
Earthquake	3.57	3.86	3.59	3.10
Landslide	3.43	3.05	3.18	3.14
Sinkhole	3.26	3.23	3.05	2.95
Wildfire	1.87	1.57	1.68	1.43
Severe Heat	1.87	1.86	1.91	1.86
Severe Cold	1.83	1.82	1.90	1.86

The results demonstrate that KYTC personnel view certain types of hazards as having a greater impact than others on the transportation system. Flooding, flash flooding, earthquakes, and landslides ranked in the top five for all criteria. Sinkholes were ranked high in terms of long-term impacts and overall impacts, while snow/ice was ranked highly for their short-term impacts and probability of impacts.

The survey results are consistent with an analysis of the FEMA disaster recovery projects in the state since 2008. Table 8 shows these projects broken down by KYTC district from 2008 to 2015. Over $16 million was used to repair transportation infrastructure damaged by flooding. Most these funds were dedicated to flood disaster recovery in District 12. Slide repair was ranked second among the expenditure categories, with nearly $1.5 million going toward slide disaster recovery.

Table 8. FEMA projects by KYTC district, 2008-2015.

District	Flood Repair for FEMA	Bridge with Grade, Drain & Surface	Operations (Maintenance)	Slide Repair	Culvert Replacement	Bridge Scour Mitigation
1		$803,766				
2						
3	$213,021					$74,160
4			$165,283			
5					$410,597	
6						
7						
8	$397,309			$294,201		
9	$469,471			$132,426		
10	$2,841,428					
11	$244,664					
12	$11,849,422			$1,069,903		

7. KYTC District 1 Vulnerability Assessment

KYTC District 1 encompasses 12 counties in far-western Kentucky (Ballard, Calloway, Carlisle, Crittenden, Fulton, Graves, Livingston, Lyon, Marshall, Hickman, McCracken, and Trigg). Ten of the twelve counties in District 1 contain at least some portion of the NHS (Carlisle and Crittenden counties do not). I-24 and I-69 are the two interstates which run through the district. It is also home to the Julian M. Carroll Purchase Parkway. Other highways include portions of US-45, US-51, US-60, US-62, US-68, US-641, KY-80, KY-121, and KY-348 (Figure 24). National Highway System assets in District 1 include:

- 296 miles of roadway
- 83 bridges
- 30 culvert locations
- 105 other structures
- Other assets
    - Lighting
    - Guardrail
    - Signals
    - Signage

A complete list of KYTC District 1 National Highway System assets is included in Appendix A.

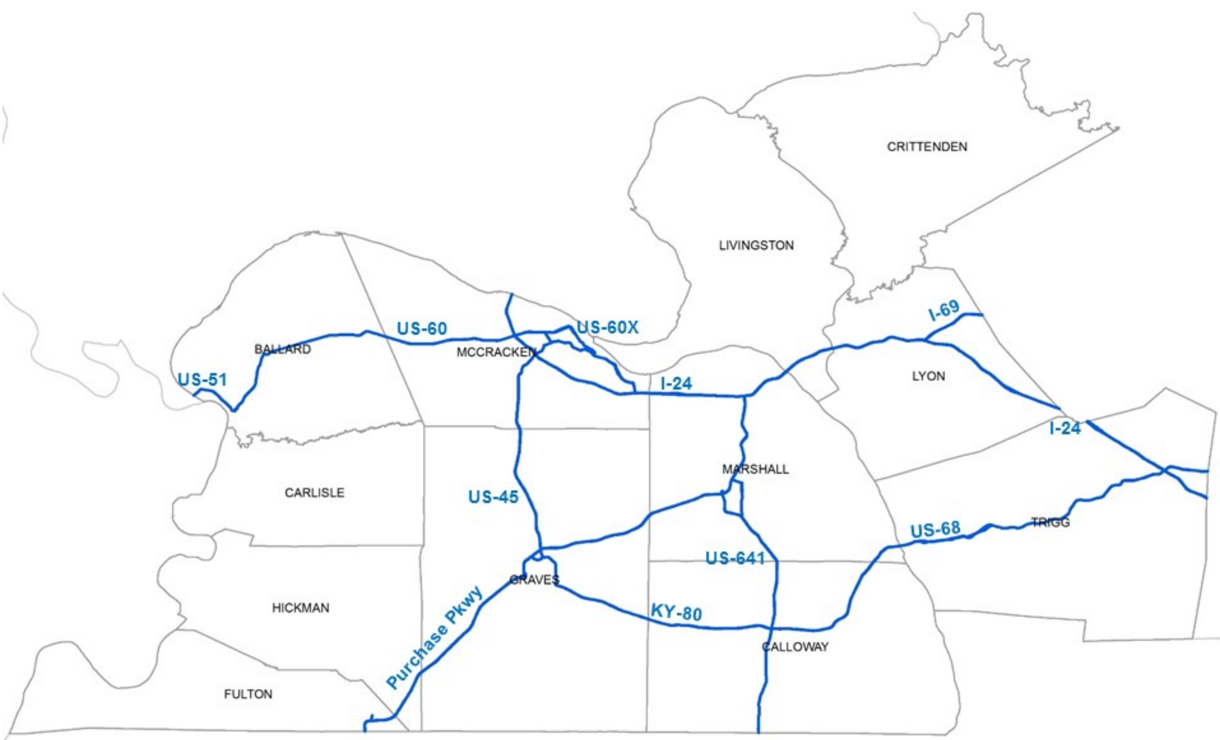


Figure 26. D1 National Highway System.

7.1. Data Gathering and Analysis

Based on the survey results presented in Chapter 6, the project team selected to be the primary focus of the district assessment the four most impactful hazards: earthquake, flood, landslide, and sinkhole. Data on each of these hazards is presented in the following sections. Aside from these hazards, other meteorological and geological hazards identified in Chapter 5 of this report were considered a secondary focus. Data and qualitative information pertaining to these hazards were collected at the workshops and is presented, where appropriate, in the subsequent section of the report.

7.1.1. Seismic Data

As discussed in Chapter 4, western Kentucky lies in close proximity to the New Madrid seismic zone. As the farthest western district in the state, District 1 is the most vulnerable to seismic activity. A significant amount of research has investigated the vulnerability of the transportation system to seismic activity, and this research informs this assessment.

Appendix D includes maps showing the probability of earthquakes of defined magnitudes for the District 1 over a 35-year period (2009-2044). These maps were produced using the USGS 2009 Earthquake Probability Mapping tool, the source model of which was the 2008 USGS-National Seismic Hazard Mapping Project (NSHMP) update.[82] The tool estimates the probability of an earthquake of greater than 8.0 occurring in this area at less than one percent.

Figure 27 shows the peak ground acceleration (PGA), expressed as a percent of gravity, with a two percent probability of exceedance in the next 50 years for District 1. Table 9 lists National Highway System assets that fall within the PGA zones.

Table 9. District 1 NHS assets by PGA zone.

PGA Zone	Miles of NHS highway	Number of NHS bridges	Number of NHS culvert locations	Number of NHS structures
1.2	13.2	7	1	0
0.8	13.3	6	4	0
0.6	82.5	20	7	39
0.5	41.7	15	6	20
0.4	82.7	22	10	24
0.3	50.6	13	2	18
0.2	11.5	0	0	4

[82] USGS, "2009 Earthquake Probability Mapping."

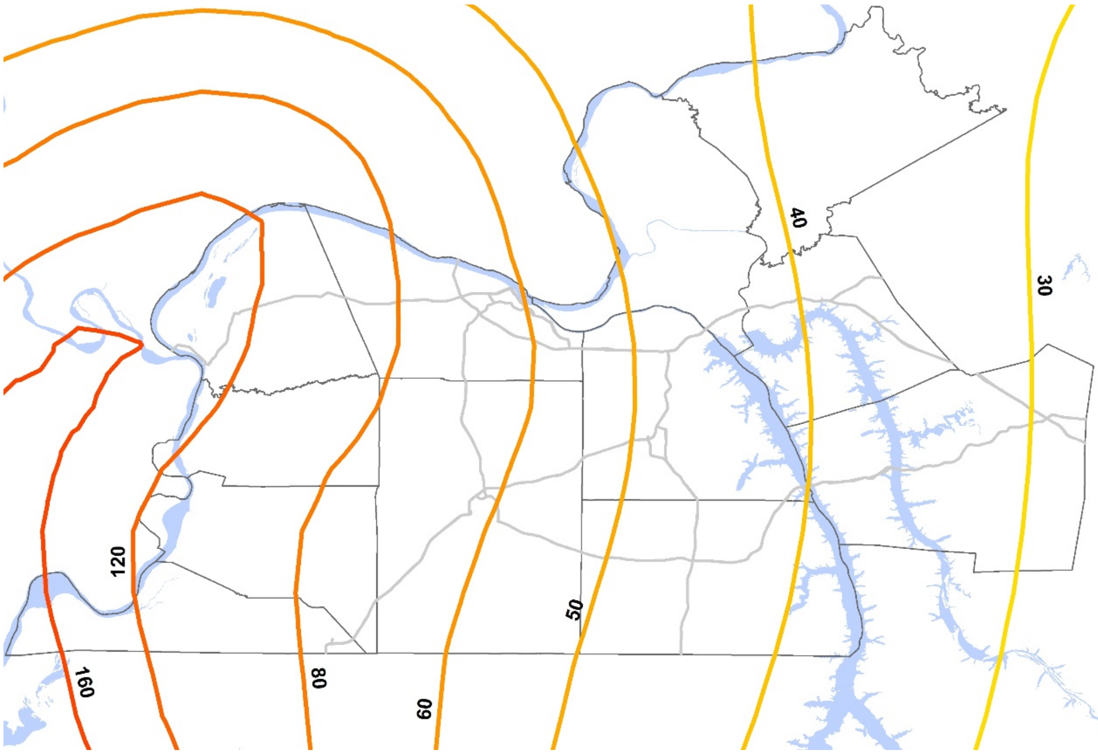


Figure 27. Peak ground acceleration with 2% probability of exceedance in 50 years. Peak acceleration expressed as a percent of gravity (%g).[83]

Previous research by KTC investigated the seismic vulnerability of over 300 bridges along the interstates and parkways of western Kentucky. Figure 28 shows the seismic rankings assigned to bridges along I-24 and Purchase Parkway in District 1. The bridge rank is calculated based on the structural vulnerability rating and the seismic hazard rating, as described in Zatar, et al.[84] The ranking ranges from 0 (lowest) to 100 (highest).

[83] USGS, “PGA 2% in 50 Yrs.”

[84] Zatar et al., “Preliminary Seismic Evaluation and Ranking of Bridges along I-24 in Western Kentucky.”

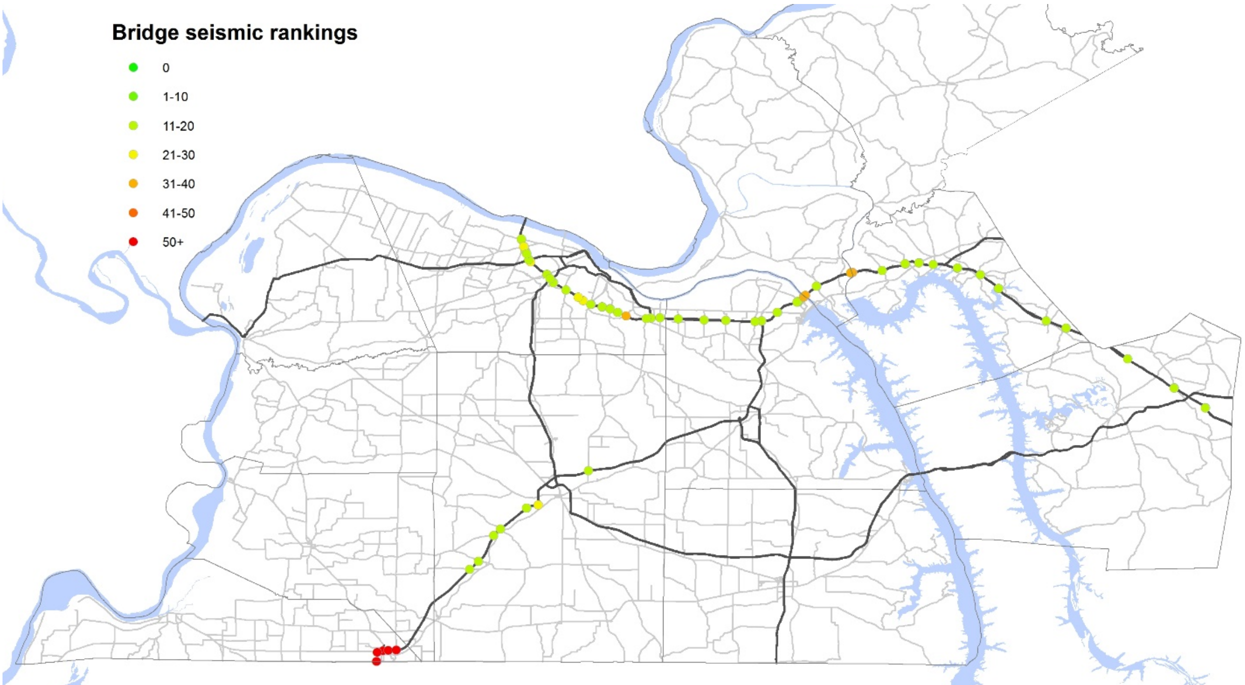


Figure 28. Bridge ranking for seismic vulnerability to 50-year event.

More in-depth seismic vulnerability analysis was conducted by KTC for large bridges in District 1. These include:

- US-51 bridge over the Ohio River north of Wickliffe, KY.
  - Seismic analysis indicated the main bridge can survive a 50-year event without damage. The approach spans are vulnerable to seismic forces, and retrofitting was recommended.[85]
- I-24 bridges over the Tennessee River in Marshall/Livingston counties.
  - The bridges were assessed for 250-year and 500-year seismic events. The main bridge can resist the 250-year and 500-year events without significant structural damage. Some bridge supports however need retrofitting to survive the 500-year event. Further, the supports of some bridge approaches need retrofitting to withstand a 250-year event, and all supports need to be retrofitted for the 500-year event. Retrofitting of the bearings on the approach span piers was recommended.[86]
- I-24 bridges over the Cumberland River in Livingston/Lyon counties.
  - Bridges were assessed for 250-year and 500-year seismic events. For the 250-year event, the main span would remain intact. On the bridge approach, pier 2 would not resist the seismic forces and a retrofit should be considered. For the 500-year event, portions of the main span would fail, and retrofitting is needed. For the bridge approach, pier 1 would resist seismic forces but pier 2 would not.[87]

[85] Harik et al., "Seismic Evaluation of the Ohio River Bridge on US 51 at Wickliffe, Kentucky."
[86] Zhao et al., "Seismic Evaluation of the Tennessee River Bridges on I-24 in Western Kentucky."
[87] Zatar, Ren, and Harik, "Seismic Evaluation of the Cumberland River Bridges on I-24 in Western Kentucky."

Additional KTC analysis assessed the seismic stability of over 400 embankments along priority routes in western Kentucky. Figure 29 shows the embankments' seismic ratings by class for District 1, as assessed by Sutterer, et al.[88] Class rankings range from A to C, where A indicates highest risk of failure during a seismic event. The Z class indicates insufficient data to conduct the assessment. Note that this research includes embankments not included in the NHS.

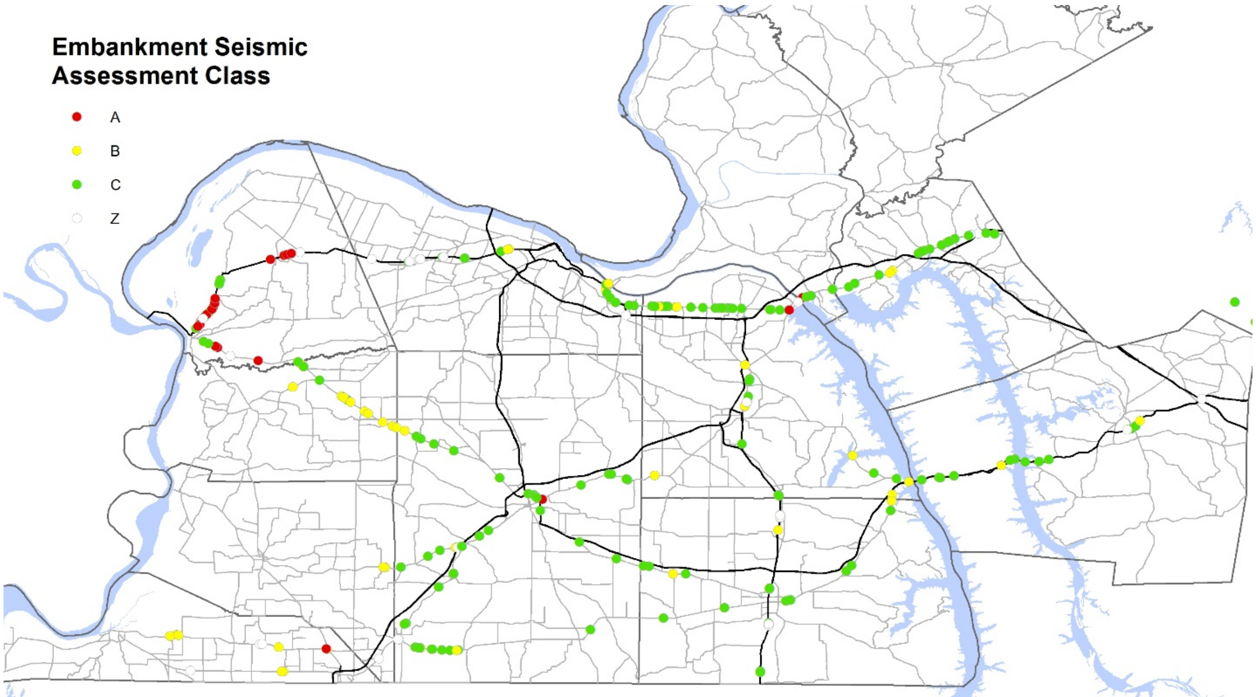


Figure 29. Seismic assessment class for highway embankments.

The embankment along US 51 north of Wickliffe was assessed separately in greater detail. For the Wickliffe approach embankment, the assessment found only marginal vulnerability to a 50-year event, but substantial vulnerability to a 500-year event.[89]

7.1.2. Flood Data

The western half of District 1 lies along the Mississippi River Alluvial Plain, which is a low lying area that includes the confluence of the Ohio and Mississippi rivers, and is also just downstream from the confluence of the Ohio, Tennessee, and Cumberland rivers. This area is vulnerable to river flooding, even if its source is hundreds of miles upstream. This region is less vulnerable to flash flooding than the eastern regions of the state, due to the relatively flat topography and its rural characteristics.

[88] Sutterer et al., "Ranking and Assessment of Seismic Stability of Highway Embankments in Kentucky."
[89] Ibid.

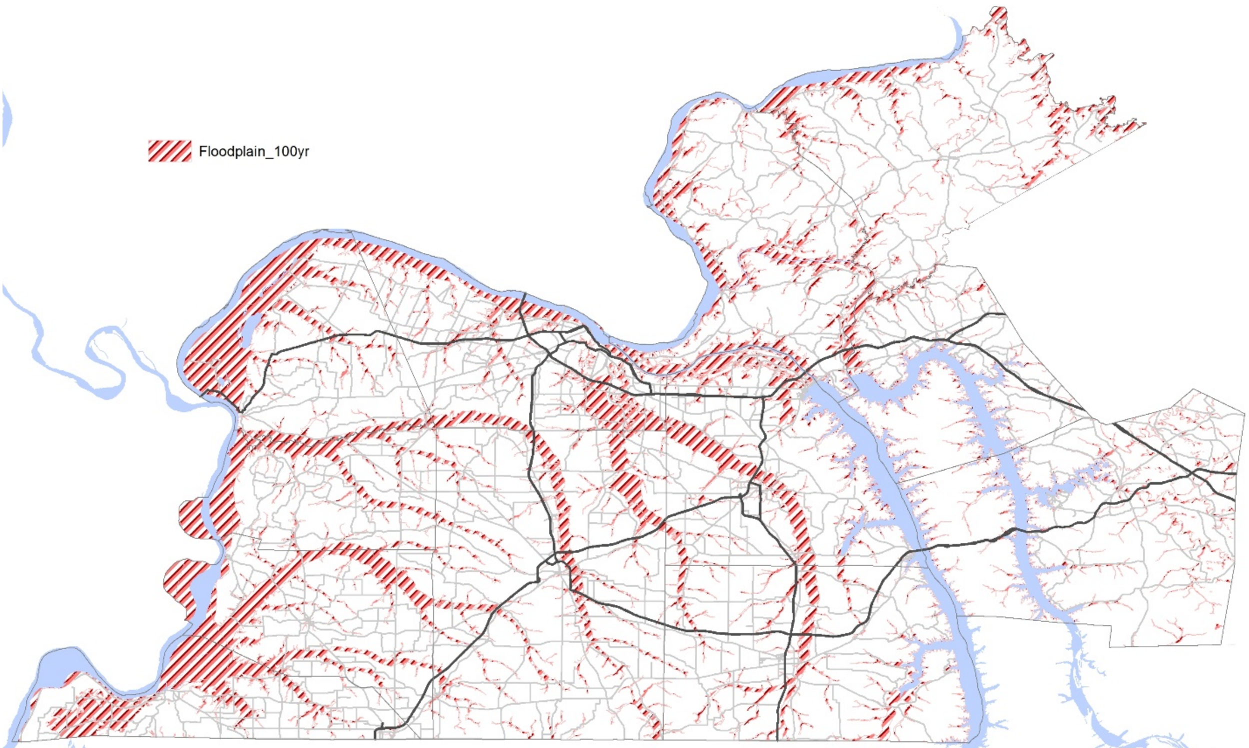


Figure 30. FEMA 100-yr floodplain in District 1.

Table 10. District 1 NHS assets located in the FEMA 100-year floodplain.

County	Miles of NHS highway	Number of NHS bridges	Number of NHS culvert locations	Number of NHS structures
Ballard	5.3	10	3	0
Calloway	3.6	22	2	0
Fulton	0.02	0	0	0
Graves	11.7	39	2	0
Livingston	3.5	1	1	0
Lyon	2.8	8	0	0
Marshall	9.8	15	8	0
McCracken	4.3	24	3	0
Trigg	6.5	10	1	0
TOTAL	47.5	129	20	0

7.1.3. Landslide Data

Of the four major hazards included in the District 1 assessment, landslides are the least likely to occur. Due to the district's relatively flat topography, landslides pose less of a threat than in other districts around the state.

Figure 31 maps landslides that KGS has documented in District 1. The landslide inventory database includes landslide information from KGS, state and local agencies, and the public.[90] Landslides are clustered at the bluffs along the Mississippi River in Hickman and Fulton counties. The map documents seven landslides along the NHS. Appendix C includes the locations and photos of these KGS-documented landslides.

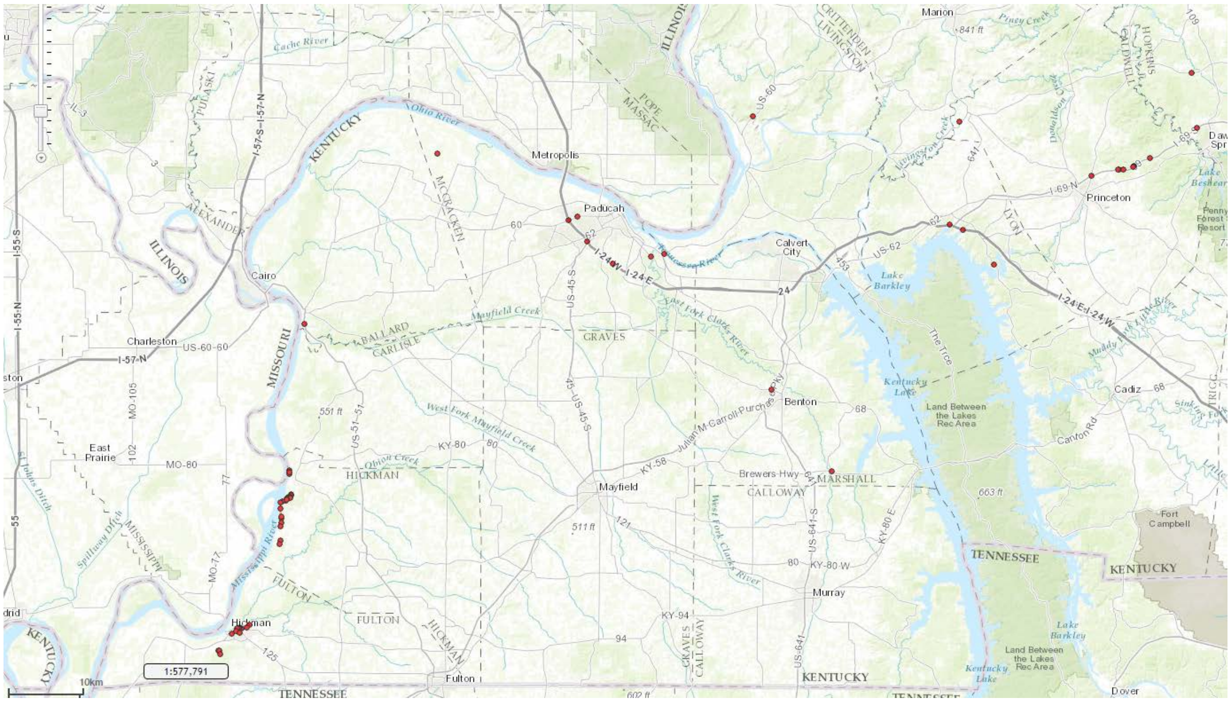


Figure 31. KGS documented landslides in District 1.[91]

7.1.4. Sinkhole Data

District 1's easternmost counties – Trigg, Lyon, Livingston, and Crittenden – are located within the Pennyroyal region of Kentucky, and therefore are subject to karst formation. Figure 32 shows the location of documented sinkholes (red), areas of high karst potential (brown), and areas of low karst potential (yellow).

[90] KGS, "Landslide Information Map."
[91] Ibid.

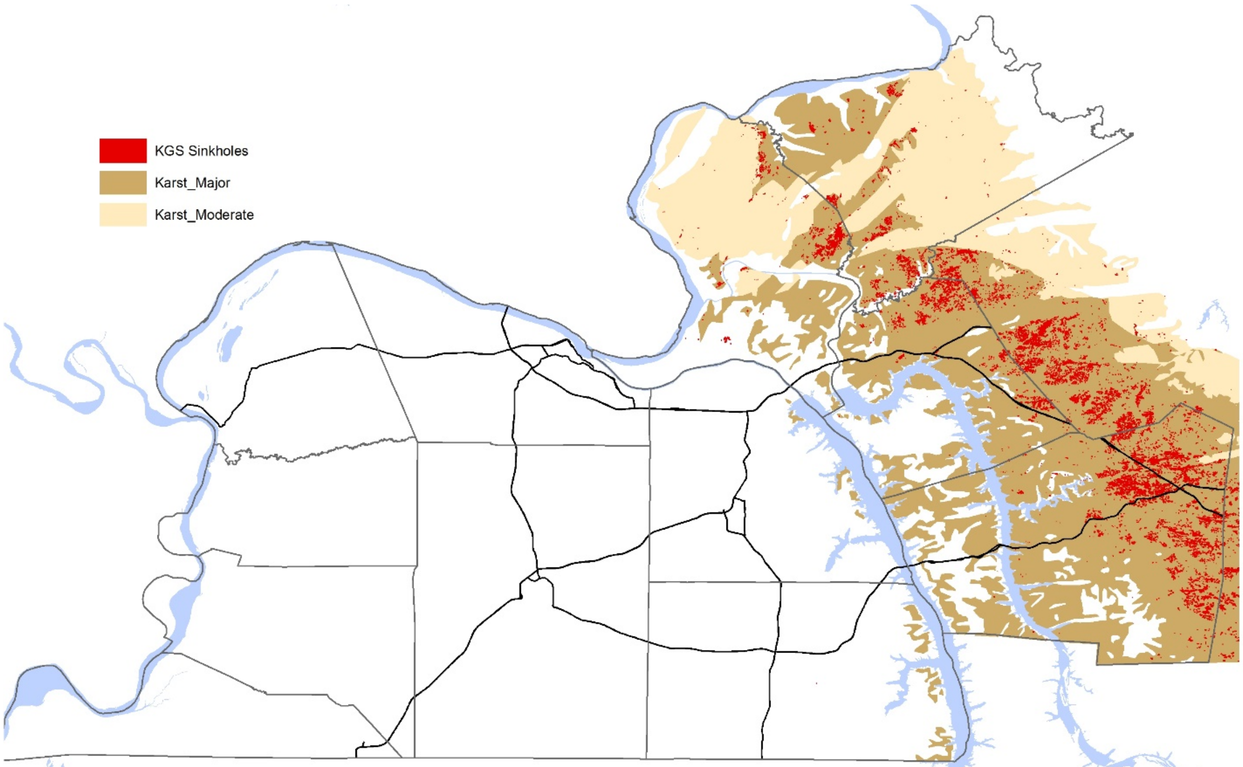


Figure 32. Karst formation in District 1.

Table 11 lists District 1 NHS assets located in areas with karst potential. Assets are listed as highway segments with the corresponding mile points.

Table 11. District 1 NHS assets located in areas of karst potential.

County	Route	MP Begin	MP End	Karst Potential
LYON	I-24	34.3	54.8	Major
LYON	I-69	0	5.6	Major
TRIGG	I-24	57.4	69.8	Major
TRIGG	US-68	1	1.4	Major
TRIGG	US-68	5.1	8.1	Major
TRIGG	US-68	8.5	28.1	Major

7.2. District 1 Workshop

In April 2016 the project team held a workshop at the District 1 headquarters in Paducah. Workshop participants included 16 KYTC maintenance officials and engineers from the district. The purpose of the workshop was to gather and incorporate local knowledge into the vulnerability assessment.

The first exercise asked participants evaluate the criticality of District 1 NHS segments using the Criticality Scale developed for this project (Figure 33). Each workshop participant recorded their response with a keypad, ranking the segment on a scale from 1 to 9. Figure 34 maps the scores for each highway segment. Participants rated the I-24 corridor as the most critical in the district. I-69 ranked second, while the remaining U.S. and state highways were consistently rated lower.

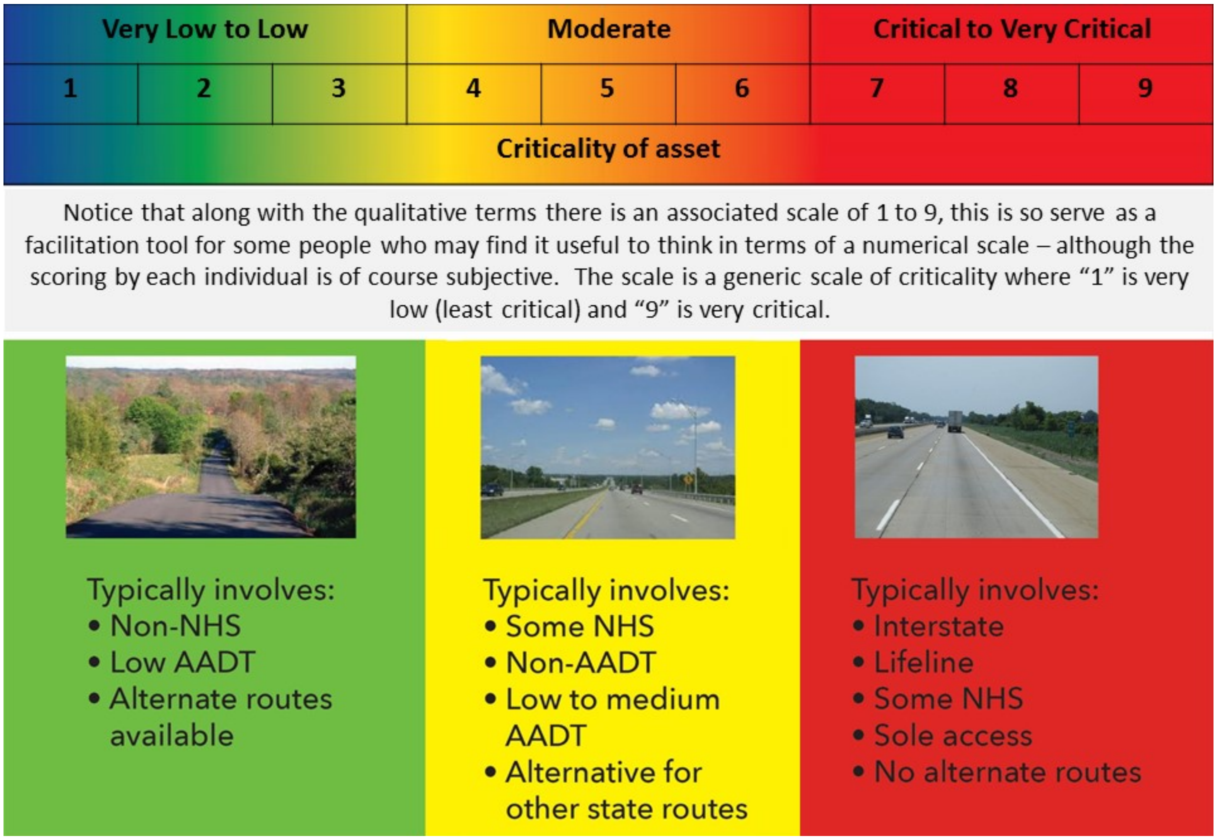


Figure 33. Criticality scale used in District 1 workshop.

Figure 34. Criticality map of District 1 NHS segments.

Since flooding was identified as one of the hazards of highest priority and concern in District 1, considerable time was spent addressing this hazard. A series of maps were developed on a countywide scale (Appendix A) to depict NHS assets in District 1 (see Appendix A). The maps included all NHS bridge locations and labeled associated bodies of water if appropriate. The maps indicated the extent of the recently updated 100-year floodplain. Printouts of these maps were provided to workshop participants, and they were asked to mark on the maps where A) highway flooding has occurred; B) highway flooding has nearly occurred; and C) highway flooding could during a high-magnitude event. Follow-up discussions let participants to share their experiences with flooding.

Figure 35 maps areas that participants believe are susceptible to flooding. Nearly every participant marked the US-51 approach and bridge over the Ohio River as an area that has flooded in the past. This bridge is located on the Ohio River floodplain and at the confluence of the Ohio and Mississippi Rivers and is periodically exposed to river flooding. Flooding here was marked as occurring on the Ohio River, Minor Slough, and Willow Slough.

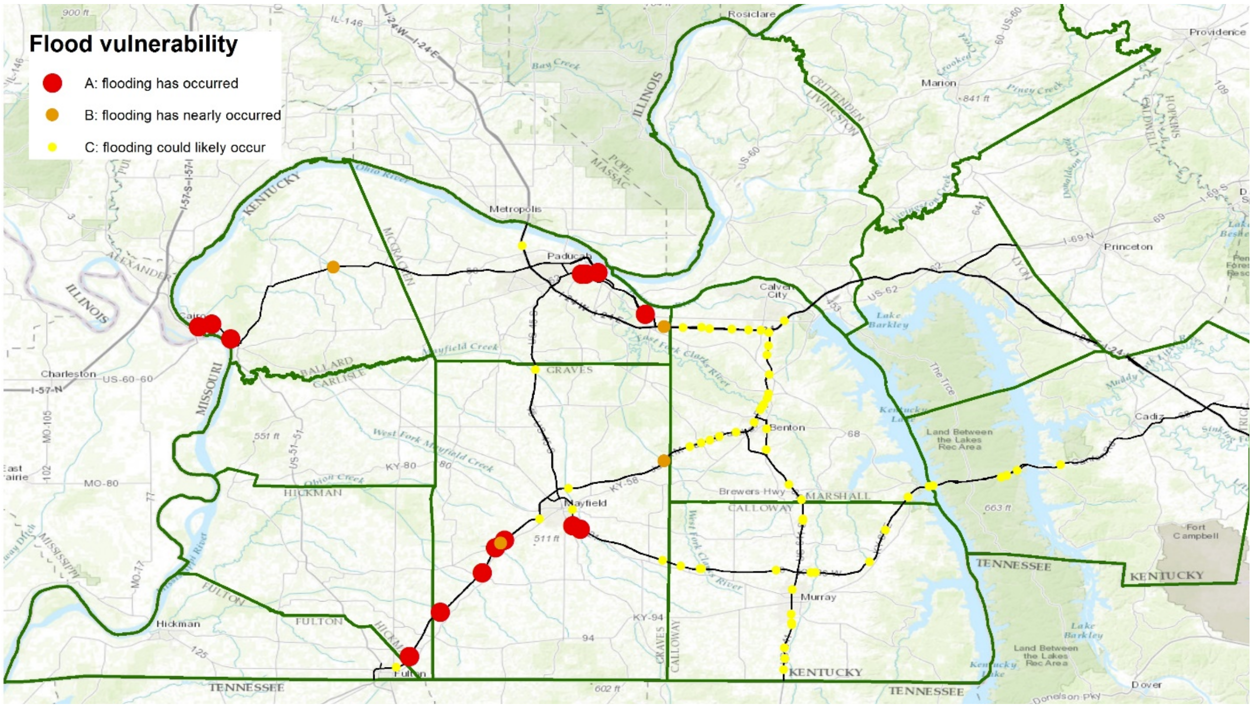


Figure 35. Results of District 1 workshop exercise on flood vulnerability.

Table 12 lists all of the areas marked by participants as having either flooded or nearly flooded. Also included in the table is the corresponding Bridge ID and Channel Rating. Channel Rating is an evaluation of the waterway's condition. The waterway is the depression that directs stream flow during non-flood conditions. It encompasses any channel protection designed to direct stream flow and protect banks from erosion and/or scour. Channel rating can range from 0 to 9, where 0 represents *Failed Condition* and 9 represents *Excellent Condition*. All ratings greater than or equal to 6 are considered *Satisfactory*, a rating of 5 is *Fair*, and a rating less than or equal to 4 denotes a *Poor* condition (or worse).

Of the 17 locations that were identified as vulnerable to flooding, one (Bridge ID 073B00130N) has a Channel Rating of 5. Twelve other locations have a Channel Rating greater than or equal to 6. Four locations do not have a Channel Rating (N/A) because the bridge does not pass directly over a waterway.

Table 12. Bridges identified in the workshop as being vulnerable to flood and the corresponding Channel Rating from the KYTC Bridge Inventory database.

Bridge ID	County	Highway	Feature Intersect	Channel Rating	Event
004B00021N	Ballard	US-51	Ohio River	7	Flooded
004B00058N	Ballard	US-60	Humphrey Creek	6	Nearly Flooded
004B00063N	Ballard	US-51	Minor Slough	6	Flooded
004B00066N	Ballard	US-51	Willow Slough	7	Flooded
042B00166L	Graves	Purchase Pkwy	W Fork Clarks River	7	Nearly Flooded
042B00170L	Graves	Purchase Pkwy	Bayou de Chien	6	Flooded
042B00174N	Graves	Purchase Pkwy	Cane Creek	6	Flooded
042B00176L	Graves	Purchase Pkwy	Obion Creek	7	Flooded
042B00177L	Graves	Purchase Pkwy	Opossum Creek	7	Flooded
042B00262N	Graves	KY-121	Kess Creek	7	Flooded
042B00279L	Graves	KY-80	Mayfield Creek	8	Flooded
053B00068N	Hickman	Purchase Pkwy	KY-2569; near Harris Fork Creek	N/A	Flooded
073B00063N	McCracken	US-62	Garrison Creek	7	Flooded
073B00064N	McCracken	I-24	KY-787; near unnamed tributary of White Oak Creek	N/A	Nearly Flooded
073B00093N	McCracken	US-60	P&L RR; along unnamed tributary west of Island Creek	N/A	Flooded
073B00094N	McCracken	US-60	P&L RR; along unnamed tributary west of Island Creek	N/A	Flooded
073B00130N	McCracken	US-60X	Island Creek	5	Flooded

Participants were next asked to assess vulnerability to geologic hazards, such as earthquakes, sinkholes, and landslides. For this exercise, large printouts of the District 1 NHS were developed that included areas of karst potential and high landslide potential. Participants were again asked to mark locations on their maps where they knew landslides or sinkholes have occurred and impacted NHS segments. No participant could recall sinkholes or landslides impacting NHS segments. Discussions during this exercise centered more on the potential impacts that could result from a large earthquake. District officials were particularly concerned with potential impacts to the US-51 bridge over the Ohio River near Wickliffe. They also expressed concern with the potential for earthquake-induced dam failure on the Tennessee or Cumberland Rivers, which would result in severe impacts. I-24 is located approximately two miles downstream of both dams, and dam failure could significant impact this route. Officials discussed concerns with potential liquefaction of highway embankments resulting from earthquake activity. The highway embankment leading up to the US-51 bridge near Wickliffe was of particular concern.

Participants were then asked to evaluate the overall impacts on the transportation system. Participants were asked to consider what they felt was the worst plausible scenario that could occur, in terms of flooding, earthquakes, landslides, and sinkholes, and then imagine what the impacts would be for this type of scenario to the NHS segments. Participants, using the Impacts Severity Scale (Figure 36), adapted from WSDOT, rated impact severity on a scale from 1 to 9, where 1 represents *Reduced Capacity* and 9 represents *Complete Failure*. Figure 37 maps the results of this exercise.

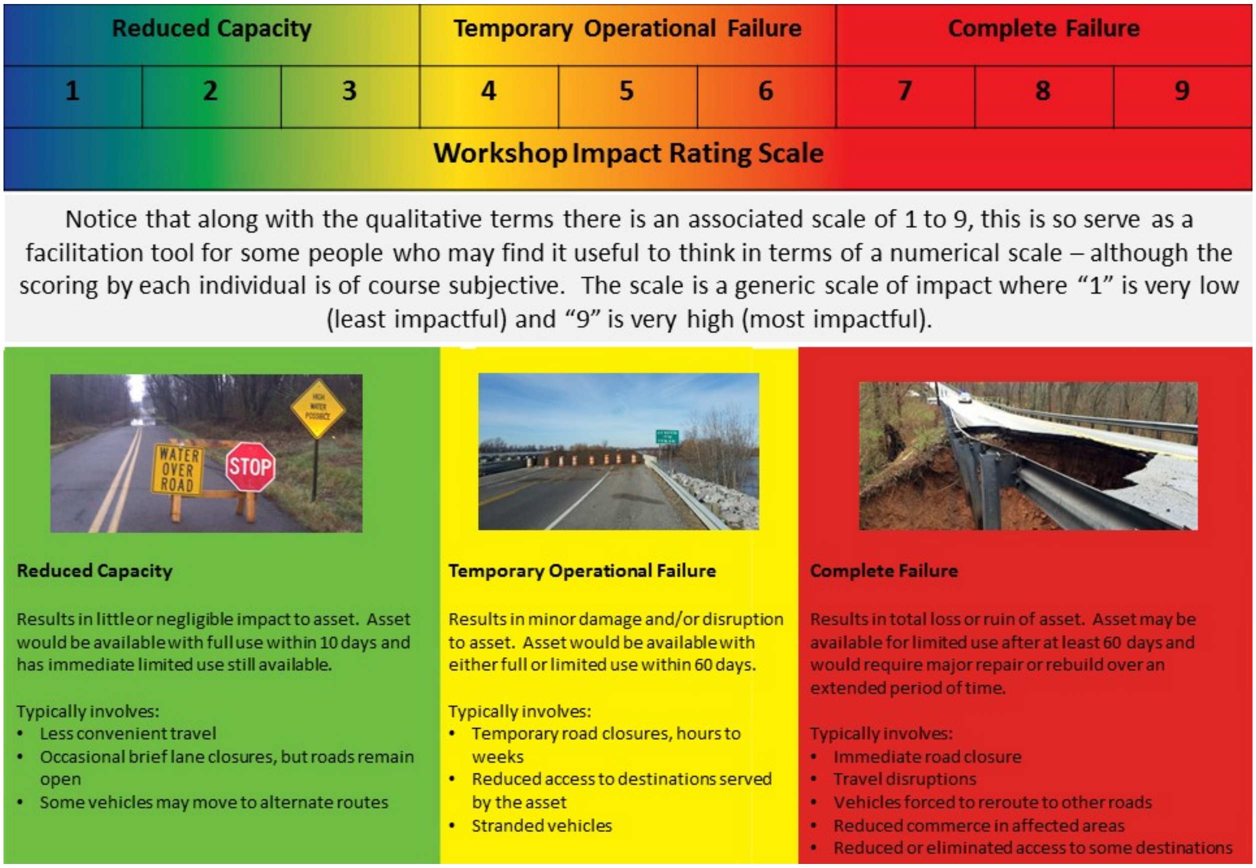


Figure 36. Impact rating scale used in District 1 workshop.

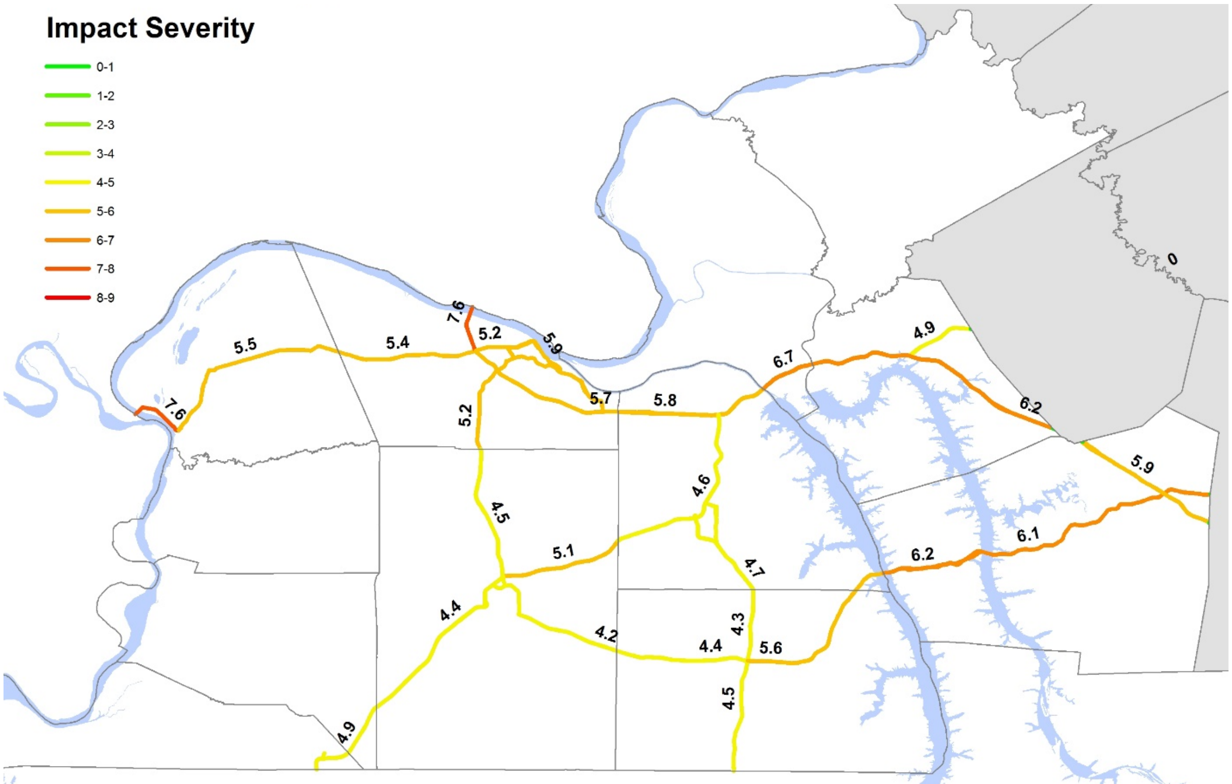


Figure 37. District 1 workshop results for severity of impacts.

The highway segments rated with the greatest impact severity ratings were US-51 approach to the Ohio River bridge north of Wickliffe and the I-24 approach to the Ohio River bridge just west of Paducah (Figure 37). Participants rated these segments highly due to the potential for damage from seismic activity. I-24 in Livingston County was ranked next. Participants indicated that the potential for dam failure at the Tennessee River and/or Cumberland River dams just upstream was the main reason. Other highly ranked segments included I-24 in Lyon and Trigg counties and US-68 in Trigg County. Participants indicated rated these segments highly due to the potential impact of sinkholes.

8. Assessment Findings

8.1. Primary Findings

Table 13. Summary of District 1 assets and associated vulnerabilities.

Hazard	Indicator	Miles of NHS	Bridges	Culverts	Structures
Earthquake	PGA zone > 120	13	7	1	0
Earthquake	PGA zone > 80	13.4	6	4	0
Earthquake	PGA zone > 60	85	20	7	39
Earthquake	50 yr event – KTC vulnerability studies	-	24	-	-
Flood	100 yr Floodplain	28.9	79	18	3
Flood	D1 Workshop	-	12	4	3
Karst	KGS Karst Major	60.9	10	2	27
Karst	KGS Karst Moderate	0	0	0	0
Landslide	KGS Landslide Inventory	(3 hwy locations)	4	0	0
Landslide	USGS Landslide High	12.7	7	1	0
Landslide	USGS Landslide Moderate	0	0	0	0

Table 13 summarizes the primary findings from the District vulnerability assessment. The table lists the total miles of NHS highway, as well as the number of bridges, culverts, and other structures, that are at risk from each hazard. The four hazards included are earthquakes, floods, karst, and landslides. Specific indicators for each hazard are described below:

- Earthquakes
  - PGA zones are areas identified by USGS where the PGA (%g) has a 2% probability of exceedance in 50 years. Table 3 shows the PGA rates and their relation to impacts to infrastructure.
  - KTC reports on the seismic vulnerability of bridges on interstates and parkways identified 24 bridges in District 1 as critically vulnerable.
- Floods
  - Assets located within the 100-year floodplain (FEMA).
  - Assets identified at the District 1 workshop as either having flooded or having nearly flooded.
- Karst
  - Areas of major and moderate karst formation as identified by KGS.
- Landslides
  - Locations in District 1 that have experienced landslides (identified by KGS).
  - Areas of high and moderate susceptibility to landslides (identified by USGS).

A full list of individual assets and their associated vulnerabilities are included in Appendix A. This list of assets was compiled into a geodatabase that was provided to KYTC as a separate deliverable.

District 1 workshop results were also used to calculate an overall vulnerability score for NHS segments. This vulnerability score was calculated by multiplying the criticality ratings by the impact severity ratings to yield an overall vulnerability rating for each NHS segment (Figure 38). By this measure, the most vulnerable assets in District 1 are:

1. US-51 in Ballard County: Ohio River approach north of Wickliffe – vulnerable to flood and earthquake
2. I-24 in McCracken County: Ohio River approach north of US-60 – vulnerable to flood and earthquake
3. I-24 in Livingston County: north of and downstream from the Kentucky Dam and Barkley Dam – vulnerable to earthquake and flooding associated with dam failure

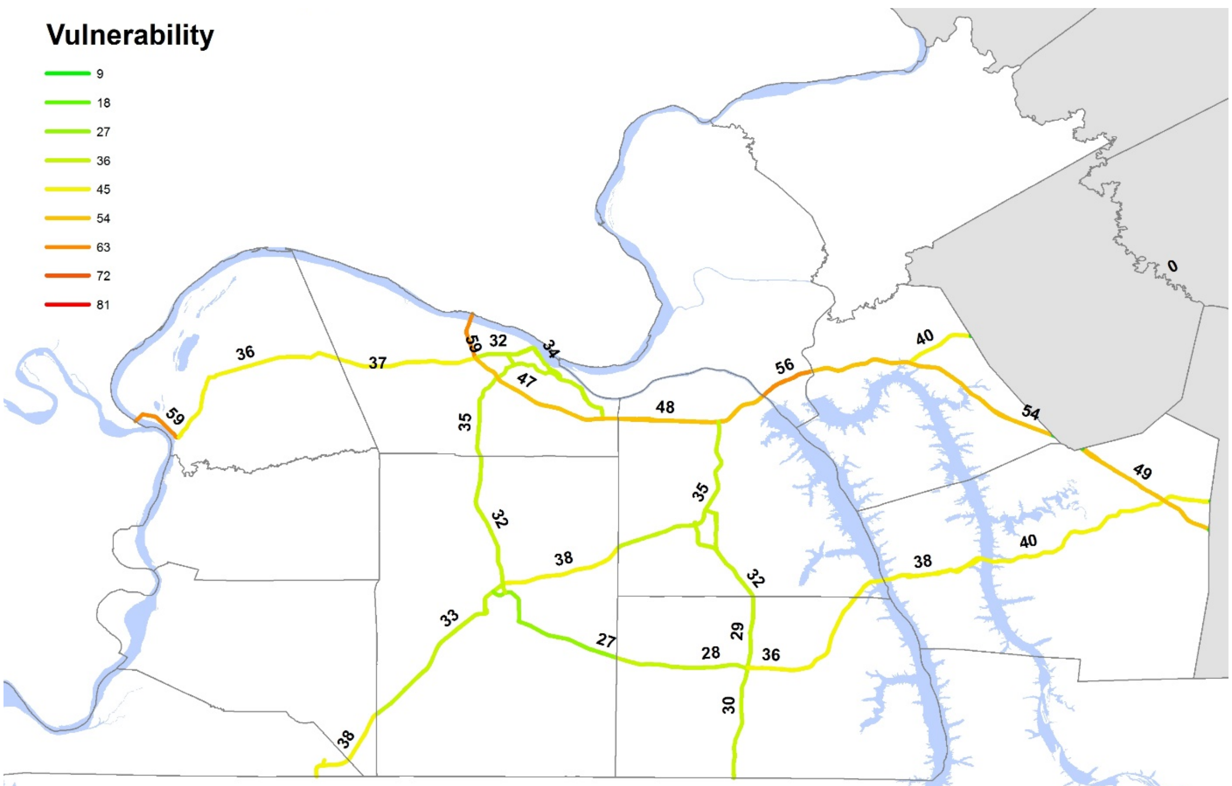


Figure 38. Vulnerability ratings, as derived from District 1 workshop.

8.2. Secondary Findings

Other issues were identified pertaining to District 1's vulnerability to natural hazards. Ledbetter is a town east of Paducah located at the confluence of the Ohio and Tennessee rivers. The town is bounded on three sides by the two rivers, and its only highway access is via US-60. Because of the town's limited highway accessibility, it is vulnerable to being cut off by major flooding. District 1 officials advised that this scenario has nearly happened in the past, and in the event of a more serious flood, could likely happen again in the future. Additionally, US-60 has been identified as a New Madrid post-incident response route that would be used to move supplies and materials to affected areas after a major earthquake.

Similarly, Wickliffe is a town located at the confluence of the Ohio and Mississippi rivers in an area prone to flooding. Wickliffe has several different highways that could be used to access the town, including US-51, US-60, KY-121, KY-286, and KY-1290, and each of these highways is vulnerable to flooding and have flooded in the past, nearly cutting off Wickliffe. During previous flood events, US-60 remained open and the only accessible highway into Wickliffe. Information gathered from the District 1 workshop indicated that one bridge on US-60 has nearly flooded in the past. Given the climate projections of greater precipitation in Kentucky, this bridge could be impacted by future floods, leaving Wickliffe entirely cutoff.

KYTC maintenance facilities for each of the twelve counties in District 1 were assessed for flood vulnerability by considering proximity to the 100 year floodplain. In Livingston County, the Smithland Section Office is in the floodplain, and the facilities flooded during the 2011 Ohio River flood. The maintenance facility grounds in McCracken County straddle a section of the 100-year floodplain, though local officials reported that the grounds have never flooded. Perimeter sections of the maintenance facility grounds in Calloway County and Graves County also lie in the 100 year floodplain. For each of these, the majority of the facility grounds are not in the floodplain. All other maintenance facilities in the district lie outside of the floodplain.

At the time of this report's writing, a major precipitation event occurred in Marshall County. One Kentucky MesoNet rain gauge recorded 8 inches of rainfall overnight. The Kentucky State Climate Center is currently working to verify this measurement. District 1 officials reported that flooding in Marshall County temporarily shut down Purchase Parkway just south of the I-24 interchange. Local roads were also flooded, and at least one bridge on a local road suffered damage.

8.3. Worst Case Scenario for District 1

The worst case natural hazards scenario for District 1 is the concurrence of a major river flood and significant earthquake. Major river flooding has the potential to disrupt traffic throughout the region, including on key bridges over the Ohio River. Workshop participants observed that several NHS roadways in the far-western part of the district are vulnerable to flooding. These areas are also located closest to the New Madrid seismic zone, where earthquake impacts are likely to be most severe. In the event that roadways are also flooded during an earthquake, emergency response and resupply efforts would be hampered. Navigable waterways, which are included as planned emergency response and resupply routes for earthquakes, would be unsafe at flood stages.

To compound this worst case scenario, if earthquake intensity were severe enough to impact the stability of dams at the Tennessee and Cumberland rivers, a resulting dam failure would release a torrent of water into Calvert City and, potentially, Paducah. It should be noted that, though the Tennessee River Dam is over 75 years old, it was designed to withstand the effects of seismic activity.[92] While seismic-induced dam failure seems like an unlikely scenario, it was of concern to workshop participants.

[92] TVA, "The Kentucky Project: A Comprehensive Report on the Planning, Design, Construction, and Initial Operation of the Kentucky Project."

9. References

Abkowitz, Mark, Janey Camp, and Leah Dundon. “Assessing the Vulnerability of Tennessee Transportation Assets to Extreme Weather.” Nashville, TN: Tennessee Department of Transportation, 2015.

Anderegg, W. R. L., J. W. Prall, J. Harold, and S. H. Schneider. “Expert Credibility in Climate Change.” *Proceedings of the National Academy of Sciences* 107, no. 27 (2010): 12107–9. doi:10.1073/pnas.1003187107.

Ashfaq, Moetasim, Laura C. Bowling, Keith Cherkauer, Jeremy S. Pal, and Noah S. Diffenbaugh. “Influence of Climate Model Biases and Daily-Scale Temperature and Precipitation Events on Hydrological Impacts Assessment: A Case Study of the United States.” *Journal of Geophysical Research* 115, no. D14 (2010). doi:10.1029/2009JD012965.

Ashfaq, Moetasim, Subimal Ghosh, Shih-Chieh Kao, Laura C. Bowling, Philip Mote, Danielle Touma, Sara A. Rauscher, and Noah S. Diffenbaugh. “Near-Term Acceleration of Hydroclimatic Change in the Western U.S.: NEAR-TERM WESTERN US SNOW.” *Journal of Geophysical Research: Atmospheres* 118, no. 19 (2013): 10,676-10,693. doi:10.1002/jgrd.50816.

Ashfaq, Moetasim, D. Rastogi, R. Mei, Shih-Chieh Kao, S. Gangrade, B. S. Naz, and Danielle Touma. “High-Resolution Ensemble Projections of near-Term Regional Climate over the Continental U.S.” *Journal for Geophysical Research-Atmospheres* Forthcoming (2016).

Berg, Robbie. “Tropical Cyclone Report: Hurricane Ike.” Miami, FL: National Hurricane Center, 2009. http://www.nhc.noaa.gov/data/tcr/AL092008_Ike.pdf.

Corfidi, Stephen F., Jeffrey S. Evans, and Robert H. Johns. “About Derechos.” *NOAA-NWS-NCEP Storm Prediction Center*, 2016. http://www.spc.noaa.gov/misc/AbtDerechos/derechofacts.htm.

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.

Diaz, John M. “Economic Impacts of Wildfire.” Southern Fire Exchange, 2014. http://fireadaptednetwork.org/wp-content/uploads/2014/03/economic_costs_of_wildfires.pdf.

DiLiberto, Tom. “‘Thousand-Year’ Downpour Led to Deadly West Virginia Floods.” *NOAA Climate.gov*, 2016. https://www.climate.gov/news-features/event-tracker/thousand-year-downpour-led-deadly-west-virginia-floods.

Doran, Peter T., and Maggie Kendall Zimmerman. “Examining the Scientific Consensus on Climate Change.” *Eos, Transactions American Geophysical Union* 90, no. 3 (2009): 22. doi:10.1029/2009EO030002.

El Dorado Weather. “Climate Atlas of the United States,” 2016. http://www.eldoradocountyweather.com/climate/US%20Climate%20Maps/us-climate-atlas-documentation.html.

FEMA. “FEMA Flood Map Service Center,” 2016. https://msc.fema.gov/portal.

FHWA. “Assessing Criticality in Transportation Adaptation Planning.” Washington DC: Federal Highway Administration, 2011.

———. “Assessment of the Body of Knowledge on Incorporating Climate Change Adaptation Measures into Transportation Projects.” Washington DC: Federal Highway Administration, 2013.

———. “Best Practices for Road Weather Management.” Washington, D.C.: Federal Highway Administration, 2002. http://www.ops.fhwa.dot.gov/publications/fhwahop12046/rwm02_alabama.htm.

———. “Climate Change & Extreme Weather Vulnerability Assessment Framework.” Washington, D.C.: Federal Highway Administration, 2012.

———. “FHWA Climate Change Resilience Pilots Peer Exchanges.” Washington DC: Federal Highway Administration, 2014.

———. “How Do Weather Events Impact Roads?” Washington, D.C.: Federal Highway Administration, 2015. http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm.

———. “National Bridge Inventory (NBI).” Washington, D.C.: Federal Highway Administration, n.d. http://www.fhwa.dot.gov/bridge/nbi.cfm.

———. “Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation’s Bridges.” Washington, D.C.: Federal Highway Administration, 1995.

———. “The Use of Climate Information in Vulnerability Assessments.” Washington DC: Federal Highway Administration, 2011.

———. *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.

Ford, Derek, and Paul Williams. *Karst Hydrogeology and Geomorphology*. West Sussex, England: John Wiley & Sons, Ltd, 2007.

Foster, Nathan. “Kentucky Normal Annual Snowfall.” Louisville, KY: National Oceanic and Atmospheric Administration, 2009. http://www.crh.noaa.gov/Image/lmk/ky_ann_snowfall.pdf.

Foster, Stuart A. “Climate Trends.” Bowling Green, KY: Kentucky Climate Center, 2016.

Frates, Michael. “Demystifying Colloquial Tornado Alley.” Akron, OH: University of Akron, 2010. http://www.uakron.edu/dotAsset/1085452.pdf.

Furgione, Laura K. “The Historic Derecho of June 29, 2012.” Service Assessment. Silver Spring, MD: National Weather Service, 2013.

Guastini, Corey T., and Lance F. Bosart. “Analysis of a Progressive Derecho Climatology and Associated Formation Environments.” *Monthly Weather Review* 144, no. 4 (2016): 1363–82. doi:10.1175/MWR-D-15-0256.1.

Hamilton, Bruce, Brian Tefft, Lindsay Arnold, and Jurek Grabowski. “Hidden Highways: Fog and Traffic Crashes on America’s Roads.” Washington, D.C.: AAA Foundation for Traffic Safety, 2014.

Harik, Issam, Chelliah Madasamy, Denglin Chen, Leonong Zhou, Kevin G. Sutterer, and Ron Street. “Seismic Evaluation of the Ohio River Bridge on US 51 at Wickliffe, Kentucky.” Lexington, KY: Kentucky Transportation Center, 1998.

ICF International. “Climate Change Vulnerability Assessment, Risk Assessment, and Adaptation Approaches.” Washington, D.C.: Federal Highway Administration, 2009. www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/vulnerability_assessment/.

———. “Integrating Climate Change into the Transportation Planning Process.” Washington DC: Federal Highway Administration, 2008.

Johnston, A. C., and E. S. Schweig. “The Enigma of the New Madrid Earthquakes of 1811-1812.” *Annual Review of Earth and Planet Science* 24 (1996): 339–84.

KGS. “Landslide Hazards in Kentucky.” Lexington, KY: Kentucky Geological Survey, 2004. https://www.uky.edu/KGS/geologichazards/landslide_factsheet.pdf.

———. “Landslide Information Map.” Lexington, KY: Kentucky Geological Survey, 2016. http://kgs.uky.edu/kgsmap/kgsgeoserver/viewer.asp?layoutid=25.

———. “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.

Meyer, Michael, Michael Flood, Jake Keller, Justin Lennon, Gary McVoy, Chris Dorney, Ken Leonard, Robert Hyman, and Joel Smith. “Volume 2: Climate Change, Extreme Weather Events, and the Highway System: Practitioner’s Guide and Research Report.” Strategic Issues Facing Transportation. Washington, D.C.: National Cooperative Highway Research Program, 2014.

Moody, Sean, and Michael Linden. “Dramatic Flash Flooding Turns Deadly in Kentucky.” *WKYT*. Lexington, KY, 2015. http://www.wkyt.com/home/headlines/One-killed-several-missing-in-Johnson-County-flooding-314784111.html.

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.

National Weather Service. “Ellicott City Historic Rain and Flash Flood - July 30, 2016.” National Weather Service, 2016. http://www.weather.gov/lwx/EllicottCityFlood2016.

———. “Heat Watch vs. Warning,” 2016. http://www.nws.noaa.gov/os/heat/ww.shtml.

———. “The Tornado Outbreak of May 20, 2013,” 2016. http://www.srh.noaa.gov/oun/?n=events-20130520.

NOAA. “Storm Prediction Center Warning Coordination Meteorologist’s Page.” National Oceanic and Atmospheric Administration, 2016. http://www.spc.noaa.gov/wcm/.

NOAA National Climatic Data Center. “State Annual and Seasonal Time Series.” National Oceanic and Atmospheric Administration, 2016. https://www.ncdc.noaa.gov/temp-and-precip/state-temps/.

NRCAN. “Fire Behaviour.” Natural Resources Canada, 2016. http://www.nrcan.gc.ca/forests/fire-insects-disturbances/fire/13145.

Nuttli, Otto W. “Seismic Wave Attenuation and Magnitude Relations for Eastern North America.” *Journal of Geophysical Research* 78, no. 5 (1973): 876–85.

NWS. “The Great Flood of 1937.” National Weather Service, 2016. http://www.weather.gov/media/lmk/pdf/flood_37/GreatFlood1937_Poster.pdf.

Orton, Alice M. “Science and Public Policy of Earthquake Hazard Mitigation in the New Madrid Seismic Zone.” University of Kentucky, 2014.

Özgan, E., S. Serin, S. Ertürk, and I. Vural. “Effects of Freezing and Thawing on the Consolidation Settlement of Soils.” *Soil Mechanics and Foundation Engineering* 52, no. 5 (2015): 247–53. doi:10.1007/s11204-015-9336-6.

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.

Sander, David, and Glen Conner. “Fact Sheet: Ohio River Floods.” Western Kentucky University, 2008. http://kyclim.wku.edu/factSheets/ohioRiver.htm.

Sutterer, Kevin G., Issam Harik, David L. Allen, and Ron Street. “Ranking and Assessment of Seismic Stability of Highway Embankments in Kentucky.” Lexington, KY: Kentucky Transportation Center, 2000.

The National Severe Storms Laboratory. “Floods.” National Oceanic and Atmospheric Administration, 2016. http://www.nssl.noaa.gov/education/svrwx101/floods/.

———. “Tornado Basics.” National Oceanic and Atmospheric Administration, 2016. http://www.nssl.noaa.gov/education/svrwx101/floods/.

TRB. “Potential Impacts of Climate Change on U.S. Transportation.” Washington, D.C.: Transportation Research Board, 2008.

TVA. “The Kentucky Project: A Comprehensive Report on the Planning, Design, Construction, and Initial Operation of the Kentucky Project.” Technical Report No. 13. United States Tennessee Valley Authority, 1951.

United States Department of Transportation. “FHWA Releases Emergency Relief Funds for Tornado-Damaged Alabama Roadways.” *Fast Lane: The Official Blog of the U.S. Secretary of Transportation*, 2011. http://usdotblog.typepad.com/secretarysblog/2011/06/emergency-relief-funds-for-alabama.html#.V30CprgrKUk.

United States Global Change Research Program. *Global Climate Change Impacts in the United States.* Edited by Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson. Cambridge University Press, 2010.

USGS. “2009 Earthquake Probability Mapping.” United States Geological Survey, 2009. http://geohazards.usgs.gov/eqprob/2009/index.php.

———. “Earthquake Glossary.” United States Geological Survey, 2016. http://earthquake.usgs.gov/learn/glossary/?term=earthquake.

———. “GeoMAC Wildland Fire Support.” United States Geological Survey, 2016. http://geomac.gov.

———. “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.

Wang, Zhenming, Issam Harik, Edward W. Woolery, Baoping Shi, and Abheetha Peiris. "Seismic-Hazard Maps and Time Histories for the Commonwealth of Kentucky." Lexington, KY: Kentucky Transportation Center, 2008.

WSDOT. "Climate Impacts Vulnerability Assessment." Olympia, WA: Washington State Department of Transportation, 2015.

Zatar, Wael, Issam Harik, Peng Yuan, and Ching Chiaw Choo. "Preliminary Seismic Evaluation and Ranking of Bridges along I-24 in Western Kentucky." Lexington, KY: Kentucky Transportation Center, 2006.

Zatar, Wael, Wei-Xin Ren, and Issam Harik. "Seismic Evaluation of the Cumberland River Bridges on I-24 in Western Kentucky." Lexington, KY: Kentucky Transportation Center, 2006.

Zhao, Tong, Wei-Xin Ren, Issam Harik, and Jin-Dong Hu. "Seismic Evaluation of the Tennessee River Bridges on I-24 in Western Kentucky." Lexington, KY: Kentucky Transportation Center, 2006.

10. Appendices

Appendix A: District 1 NHS Assets and Hazards

Highway Segments

County	Route	Description	Miles	PGA Zone	Karst Potential	Landslide Susceptibility	Floodplain	Workshop Vulnerability Score	Workshop Vulnerability Ranking
Ballard	US 51	US 60 Ohio River approach from Wickliffe	4.58	120		High	MP Range 3.99 to 8.3	59.48	2
Ballard	US 60	US 60 east of Wickliffe in Ballard County	16.86	120 (MP 0 to 8.43); 80 (MP 8.43 to 16.94)		High (MP 0 to 8.16); Low (MP 8.16 to 16.94)	MP Range 1.49 to 12.6	36.08	15
Calloway	KY 80	KY-80 in west Calloway County	10.2	50 (MP 0 to 2.38); 40 (MP 2.38 to 10.2)		Low	MP Range 2.44 to 10.2	28.15	25
Calloway	KY 80	KY-80/US-68 in east Calloway/Marshall County	12.45	40 (MP 10.2 to 22.68)		Low	MP Range 10.2 to 19.81	36.21	14
Calloway	US 641	US-641 in north Calloway County	6.8	40		Low	MP Range 10.6 to 16.05	29.25	24
Calloway	US 641	US-641 in Murray and south Calloway County	10.63	40		Low	MP Range 0.92 to 10.6	29.89	23
Fulton	CR 1013	Purchase Pkwy in Fulton/Hickman	0.03	60		Low		38.40	10

		Counties; Amtrak Access							
Fulton	JC 9003	Purchase Pkwy in Fulton/Hickman Counties; Amtrak Access	3.47	60		Low	MP Range 2.66 to 2.69	38.40	10
Fulton	US 51	Purchase Pkwy in Fulton/Hickman Counties; Amtrak Access	0.56	60		Low		38.40	10
Graves	JC 9003	Purchase Pkwy in west Graves County	11.78	60 (MP 8.35 to 23.7)		Low	MP Range 9.01 to 23.7	33.28	19
Graves	JC 9003	Purchase Pkwy in east Graves County	10.84	60 (MP 23.7 to 26.39); 50 (MP 26.39 to 34.49)		Low	MP Range 23.7 to 34.14	38.00	11
Graves	KY 121	KY-80/KY-121 in Mayfield and east Graves County	4.58	50 (MP 5.5 to 7.71); 60 (MP 7.71 to 10.08)		Low	MP Range 5.5 to 9.29	26.87	26
Graves	KY 80	KY-80/KY-121 in Mayfield and east Graves County	8.31	50		Low	MP Range 12.86 to 20.72	26.87	26
Graves	US 45	US-45 in north Graves County	13.37	60		Low	MP Range 18.35 to 31.25	32.10	22
Hickman	JC 9003	Purchase Pkwy in Fulton/Hickman Counties; Amtrak Access	4.88	60		Low		38.40	10

Livingston	I 24	I-24 in Livingston County	4.5	40		Low	MP Range 29.35 to 33.88	56.40	3
Lyon	I 24	I-24 in Lyon County	20.97	40 (MP 33.88 to 38.78); 30 (MP 38.78 to 54.84)	Major (MP 34.27 to 54.84)	Low	MP Range 33.88 to 53.49	53.74	4
Lyon	I 69	I-69 in Lyon County	5.64	30	Major (MP 68.08 to 73.69)	Low	MP Range 73.04 to 73.05	40.09	8
Marshall	I 24	I-24 in Marshall County	12.03	50 (MP 17.32 to 21.93); 40 (MP 21.93 to 29.35)		Low	MP Range 19.58 to 29.35	48.21	6
Marshall	JC 9003	Purchase Pkwy in Marshall County	16.95	50 (MP 34.49 to 39.32); 40 (MP 39.32 to 51.4)		Low	MP Range 37.14 to 51.18	34.62	17
Marshall	KY 348	US-641/641S/KY 348 in Marshall County	0.86	40		Low	MP Range 7.8 to 8.26	32.41	21
Marshall	KY 80	KY-80/US-68 in east Calloway/Marshall County	1.94	40		Low	MP Range 0.54 to 1.82	36.21	14
Marshall	US 0641S	US-641/641S/KY 348 in Marshall County	3.53	40		Low		32.41	21
Marshall	US 641	US-641/641S/KY 348 in Marshall County	9.78	40		Low	MP Range 0.16 to 8	32.41	21
Marshall	US 68	KY-80/US-68 in east Calloway/Marshall County	0.94	40 (MP 27.23 to 28.12); 30 (MP 28.12 to 28.15)		Low	MP Range 27.49 to 28.15	36.21	14

McCracken	I 24	I-24 in McCracken County south of US-60	12.89	60 (MP 4.4 to 12.65); 50 (MP 12.65 to 17.32)		Low	MP Range 0 to 14.31	46.75	7
McCracken	I 24	I-24 Ohio River approach from US-60	4.4	60		Low		59.49	1
McCracken	US 0045X	US-60X/US 45X in Paducah	1.58	60		Low		33.78	18
McCracken	US 0060X	US-60X/US 45X in Paducah	6.65	60 (MP 0 to 3.89); 50 (MP 3.89 to 5.07)		Low		33.78	18
McCracken	US 45	US-45 in south McCracken County	10.8	60		Low	MP Range 8.06 to 8.06	35.02	16
McCracken	US 60	US 60 McCracken County west of I-24	20.03	80 (MP 0 to 4.94); 60 (MP 4.94 to 16.75); 50 (MP 16.75 to 20.02)		Low	MP Range 1.32 to 19.25	36.62	13
McCracken	US 62	US-62/68 in Paducah inside I-24	2	50		Low	MP Range 14.14 to 14.16	32.48	20
McCracken	US 68	US-62/68 in Paducah inside I-24	0.99	50		Low		32.48	20
Trigg	I 24	I-24 in Trigg County	12.48	30 (MP 57.39 to 63.65); 20 (MP 63.65 to 69.83)	Major (MP 57.39 to 69.83)	Low	MP Range 59.4 to 68.27	49.24	5
Trigg	US 68	US-68 in the Land Between the Lakes	8.88	30	Major (MP 1.05 to 1.4, 5.18 to 8.88)	Low	MP Range 0 to 8.88	37.74	12

Trigg	US 68	US-68 in Trigg County east of the lakes	19.24	30 (MP 8.88 to 22.8); 20 (MP 22.8 to 28.13)	Major (8.88 to 28.13)	Low	MP Range 8.88 to 26.86	39.70	9

Bridges

County	Route	Mid MP	Bridge ID	Feature Intersect	Type	PGA Zone	Karst Potential	Landslide Potential	Sinkhole	Floodplain
Ballard	US 51	7.948	004B00021	OHIO RIVER -IC (SOU) RR	Bridge	120		High	0	1
Ballard	US 51	6.693	004B00063	MINOR SLOUGH	Bridge	120		High	0	1
Ballard	US 51	4.56	004B00066	WILLOW SLOUGH	Bridge	120		High	0	1
Ballard	US 60	5.547	004B00005	DRAINAGE DITCH	Culvert	120		High	0	1
Ballard	US 60	15.866	004B00013	PAGE BRANCH	Culvert	80		Low	0	0
Ballard	US 60	12.515	004B00012	BRANCH FRAZIER CREEK	Culvert	80		Low	0	1
Ballard	US 60	12.475	004B00011	FRAZIER CREEK	Culvert	80		Low	0	1
Ballard	US 60	5.309	004B00062	LITTLE SHAWNEE CREEK	Bridge	120		High	0	1
Ballard	US 60	11.519	004B00057	FORK OF HUMPHREY CR	Bridge	80		Low	0	1
Ballard	US 60	2.491	004B00061	BIG CANE CREEK	Bridge	120		High	0	1
Ballard	US 60	1.955	004B00056	SOUTH FORK-CANE CREEK	Bridge	120		High	0	1
Ballard	US 60	10.222	004B00064	W.FK. HUMPHREY CREEK	Bridge	80		Low	0	1
Ballard	US 60	11.818	004B00058	HUMPHREY CREEK	Bridge	80		Low	0	1
Ballard	US 60	5.743	004B00059	SHAWNEE CREEK	Bridge	120		High	0	1
Calloway	KY 80	11.266	018B00129	BRIDGE OVER UNNAM CREEK	Bridge	40		Low	0	1
Calloway	KY 80	19.731	018B00131	LITTLE JONATHAN CREEK	Bridge	40		Low	0	1

Calloway	KY 80	0.996	018B00134	SAND LICK BRANCH	Bridge	50		Low	0	0
Calloway	KY 80	2.678	018B00138	WEST FORK OF CLARKS RIVR	Bridge	40		Low	0	1
Calloway	KY 80	11.612	018B00130	FORK OF CLARKS RIVER	Bridge	40		Low	0	1
Calloway	KY 80	8.494	018B00139	ROCKHOUSE CREEK	Bridge	40		Low	0	1
Calloway	KY 80	16.339	018B00133	JONATHAN CREEK	Bridge	40		Low	0	1
Calloway	KY 80	2.559	018B00137	W FORK CLARKS RVR OVERFL	Bridge	40		Low	0	1
Calloway	US 641	2.173	018B00031	MORRIS BRANCH	Culvert	40		Low	0	1
Calloway	US 641	3.197	018B00030	POYNER BRANCH	Culvert	40		Low	0	0
Calloway	US 641	6.513	018B00027	COLBURN BRANCH	Culvert	40		Low	0	1
Calloway	US 641	1.121	018B00112	BRUSHY CREEK	Bridge	40		Low	0	1
Calloway	US 641	15.82	018B00096	ROCKHOUSE CRK OVERFLOW	Bridge	40		Low	0	1
Calloway	US 641	5.683	018B00106	CLARKS RIVER	Bridge	40		Low	0	1
Calloway	US 641	8.916	018B00111	BEE CREEK	Bridge	40		Low	0	1
Calloway	US 641	15.651	018B00095	ROCKHOUSE CREEK	Bridge	40		Low	0	1
Calloway	US 641	5.503	018B00105	TRIB-MID.FK.CLARKS RIVER	Bridge	40		Low	0	1
Fulton	JC 9003	2.659	038B00056	HARRIS FORK	Culvert	60		Low	0	0
Fulton	JC 9003	1.818	038B00055	IC (NOR) & (SOU) RAILROA	Structure	60		Low	0	0
Fulton	JC 9003	0.004	038B00053	KY 116	Structure	60		Low	0	0
Fulton	JC 9003	2.444	038B00015	JACKSON PURCHASE PARKWAY	Structure	60		Low	0	0
Fulton	JC 9003	1.425	038B00012	JACKSON PURCHASE PARKWAY	Structure	60		Low	0	0
Fulton	JC 9003	0.929	038B00054	KY 166	Structure	60		Low	0	0
Graves	JC 9003	14.156	042B00174	CANE CREEK	Culvert	60		Low	0	1
Graves	JC 9003	25.425	042B00157	MAYFIELD CREEK	Bridge	60		Low	0	1

Graves	JC 9003	9.114	042B00170	BAYOU DE CHIEN	Bridge	60		Low	0	1
Graves	JC 9003	25.647	042B00158	MAYFIELD CREEK OVERFLOW	Bridge	60		Low	0	1
Graves	JC 9003	17.797	042B00177	OPOSSUM CREEK	Bridge	60		Low	0	1
Graves	JC 9003	16.768	042B00176	OBION CREEK	Bridge	60		Low	0	1
Graves	JC 9003	33.531	042B00165	CLARKS RIVER OVERFLOW	Bridge	50		Low	0	1
Graves	JC 9003	33.706	042B00166	WEST FORK CLARKS RIVER	Bridge	50		Low	0	1
Graves	JC 9003	12.798	042B00173	BRUSH CREEK	Bridge	60		Low	0	1
Graves	JC 9003	34.02	042B00167	CLARKS RIVER OVERFLOW	Bridge	50		Low	0	1
Graves	JC 9003	31.582	042B00163	PANTHER CREEK OVERFLOW	Bridge	50		Low	0	0
Graves	JC 9003	31.42	042B00162	PANTHER CREEK	Bridge	50		Low	0	1
Graves	JC 9003	25.873	042B00159	MAYFIELD CREEK OVERFLOW	Bridge	60		Low	0	1
Graves	JC 9003	8.353	053B00102	JACKSON PURCHASE PARKWAY	Structure	60		Low	0	0
Graves	JC 9003	13.653	042B00143	JACKSON PURCHASE PARKWAY	Structure	60		Low	0	0
Graves	JC 9003	17.357	042B00128	JACKSON PURCHASE PARKWAY	Structure	60		Low	0	0
Graves	JC 9003	26.576	042B00160	JACKSON PURCHASE PARKWAY	Structure	50		Low	0	0
Graves	JC 9003	11.428	042B00172	JACKSON PURCHASE PARKWAY	Structure	60		Low	0	0
Graves	JC 9003	21.305	042B00154	MAYFIELD BY-PASS	Structure	60		Low	0	0
Graves	JC 9003	25.085	042B00156	P&L RAILWAY	Structure	60		Low	0	0
Graves	JC 9003	34.35	042B00168	KY 564	Structure	50		Low	0	0
Graves	JC 9003	20.299	042B00153	JACKSON PURCHASE PARKWAY	Structure	60		Low	0	0

Graves	JC 9003	15.298	042B00175	JACKSON PURCHASE PARKWAY	Structure	60		Low	0	0
Graves	JC 9003	16.533	042B00096	JACKSON PURCHASE PARKWAY	Structure	60		Low	0	0
Graves	JC 9003	27.472	042B00009	JACKSON PURCHASE PARKWAY	Structure	50		Low	0	0
Graves	JC 9003	23.723	042B00274	OVER JULIAN CARROLL PW	Structure	60		Low	0	0
Graves	JC 9003	31.131	042B00028	JACKSON PURCHASE PARKWAY	Structure	50		Low	0	0
Graves	JC 9003	10.181	042B00171	JACKSON PURCHASE PARKWAY	Structure	60		Low	0	0
Graves	JC 9003	12.607	042B00180	JACKSON PURCHASE PARKWAY	Structure	60		Low	0	0
Graves	JC 9003	32.734	042B00164	JACKSON PURCHASE PARKWAY	Structure	50		Low	0	0
Graves	JC 9003	28.235	042B00161	JACKSON PURCHASE PARKWAY	Structure	50		Low	0	0
Graves	KY 121	9.255	042B00264	OAK GROVE CREEK	Culvert	60		Low	0	0
Graves	KY 121	5.581	042B00262	KESS CREEK	Bridge	50		Low	0	1
Graves	KY 121	7.154	042B00263	RED DUCK CREEK	Bridge	50		Low	0	1
Graves	KY 80	14.884	042B00281	UNNAMED STREAM	Culvert	50		Low	0	1
Graves	KY 80	20.651	042B00280	MINNOW BRANCH	Bridge	50		Low	0	1
Graves	KY 80	13.537	042B00279	MAYFIELD CREEK	Bridge	50		Low	0	1
Graves	KY 80	13.368	042B00278	MAYFIELD CREEK OVERFLOW	Bridge	50		Low	0	1
Graves	KY 80	13.226	042B00277	MAYFIELD CREEK OVERFLOW	Bridge	50		Low	0	1
Graves	US 45	20.232	042B00008	KEY CREEK	Bridge	60		Low	0	1
Graves	US 45	24.356	042B00214	STAFFORDS CREEK	Bridge	60		Low	0	1

Graves	US 45	31.034	042B00213	MAYFIELD CREEK	Bridge	60		Low	0	0
Graves	US 45	30.687	042B00212	MAYFIELD CREEK	Bridge	60		Low	0	1
Graves	US 45	18.368	042B00258	OAK GROVE CREEK	Bridge	60		Low	0	1
Graves	US 45	19.076	042B00155	US 45	Structure	60		Low	0	0
Hickman	JC 9003	6.533	053B00056	JACKSON PURCHASE PARKWAY	Structure	60		Low	0	0
Hickman	JC 9003	4.152	053B00068	JACKSON PURCHASE PARKWAY	Structure	60		Low	0	0
Hickman	JC 9003	5.122	053B00050	JACKSON PURCHASE PARKWAY	Structure	60		Low	0	0
Livingston	I 24	32.184	070B00061	CREVASSEE CREEK	Culvert	40		Low	0	1
Livingston	I 24	32.947	070B00062	KY 917	Structure	40		Low	0	1
Livingston	I 24	30.742	070B00064	I-24 @ MP. 030.721	Structure	40		Low	0	0
Lyon	I 24	40.841	072B00039	KNOB CREEK	Bridge	30	Major	Low	0	1
Lyon	I 24	53.44	072B00048	DRY FORK CREEK	Bridge	30	Major	Low	0	1
Lyon	I 24	46.673	072B00044	EDDY CREEK	Bridge	30		Low	0	1
Lyon	I 24	33.939	070B00063	CUMBERLAND RIVER	Bridge	40		Low	0	1
Lyon	I 24	44.687	072B00043	I-24 @ MP. 044.693	Structure	30	Major	Low	0	0
Lyon	I 24	49.455	072B00045	I 24	Structure	30	Major	Low	0	0
Lyon	I 24	40.715	072B00038	I 24 @ MP 40.720	Structure	30	Major	Low	0	0
Lyon	I 24	37.291	072B00034	I-24 @ MP. 037.288	Structure	40	Major	Low	0	0
Lyon	I 24	51.7	072B00047	I 24 @ MP. 51.718	Structure	30	Major	Low	0	0
Lyon	I 24	50.634	072B00058	I-24 @ MP. 050.701	Structure	30	Major	Low	0	0
Lyon	I 24	50.689	072B00046	I-24 @ MP. 050.701	Structure	30	Major	Low	0	0
Lyon	I 24	42.041	072B00040	I-24 @ MP. 042.048	Structure	30	Major	Low	0	0

Lyon	I 24	35.286	072B00032	I-24 @ MP. 035.289	Structure	40	Major	Low	0	0
Lyon	I 24	37.976	072B00035	P&L RAILWAY	Structure	40	Major	Low	0	0
Lyon	I 24	0.008	072B00049	I-24 @ MP. 041.603	Structure	30	Major	Low	0	0
Lyon	I 24	43.685	072B00042	I-24 @ MP. 043.711	Structure	30	Major	Low	0	0
Lyon	I 24	39.542	072B00037	US 62	Structure	30	Major	Low	0	0
Lyon	I 24	42.677	072B00041	PORT AUTHORITY RD	Structure	30	Major	Low	0	1
Lyon	I 24	36.399	072B00033	I-24 @ MP. 036.406	Structure	40	Major	Low	0	0
Lyon	I 24	38.365	072B00036	KY 93	Structure	40	Major	Low	0	0
Lyon	I 69	69.812	072B00051	RILEY ROAD	Culvert	30	Major	Low	0	0
Lyon	I 69	0.187	072B00052	P&L RR-ELKHORN TAVERN RD	Structure	30	Major	Low	0	0
Lyon	I 69	68.915	072B00050	WESTERN KY PKWAY @ .855	Structure	30	Major	Low	0	0
Lyon	I 69	73.647	072B00029	WESTERN KENTUCKY PARKWAY	Structure	30	Major	Low	0	0
Lyon	I 69	71.772	072B00030	US 62	Structure	30	Major	Low	0	0
Marshall	I 24	19.719	079B00082	LITTLE CYPRESS CREEK	Culvert	50		Low	0	0
Marshall	I 24	24.376	079B00136	BR- LITTLE JOHN CK	Culvert	40		Low	0	0
Marshall	I 24	29.242	079B00118	TENNESSEE RIVER	Bridge	40		Low	0	1
Marshall	I 24	27.573	079B00115	CYPRESS CREEK CANAL	Bridge	40		Low	0	1
Marshall	I 24	20.359	079B00092	I 24	Structure	50		Low	0	0
Marshall	I 24	26.579	079B00113	US 62	Structure	40		Low	0	0
Marshall	I 24	24.425	079B00109	I-24 @.MP. 024.419	Structure	40		Low	0	0
Marshall	I 24	28.679	079B00117	KY. 282	Structure	40		Low	0	1
Marshall	I 24	28.516	079B00116	P&L RAILWAY	Structure	40		Low	0	0
Marshall	I 24	22.125	079B00111	I-24 @.MP. 022.112	Structure	40		Low	0	0

Marshall	I 24	18.309	079B00149	I 24	Structure	50		Low	0	0
Marshall	I 24	18.328	079B00081	I 24	Structure	50		Low	0	0
Marshall	I 24	23.397	079B00112	-24 @.MP. 023.393	Structure	40		Low	0	0
Marshall	JC 9003	37.155	079B00070	MIDDLE FORK CREEK	Culvert	50		Low	0	1
Marshall	JC 9003	38.673	079B00072	GIBSON CREEK	Culvert	50		Low	0	1
Marshall	JC 9003	51.141	079B00067	LITTLE JOHN CREEK	Culvert	40		Low	0	1
Marshall	JC 9003	37.14	079B00069	KY 1949	Culvert	50		Low	0	0
Marshall	JC 9003	44.582	079B00065	OLD BENTON-BRIENSBURG RD	Culvert	40		Low	0	0
Marshall	JC 9003	43.909	079B00064	CLARKS RIVER RELIEF	Bridge	40		Low	0	1
Marshall	JC 9003	43.303	079B00075	CLARKS RIVER RELIEF	Bridge	40		Low	0	1
Marshall	JC 9003	43.663	079B00076	EAST FORK CLARKS RIVER	Bridge	40		Low	0	1
Marshall	JC 9003	37.873	079B00071	JACKSON PURCHASE PARKWAY	Structure	50		Low	0	0
Marshall	JC 9003	42.762	079B00074	Abandoned RR	Structure	40		Low	0	0
Marshall	JC 9003	49.829	079B00066	JACKSON PURCHASE PARKWAY	Structure	40		Low	0	0
Marshall	JC 9003	36.202	079B00068	JACKSON PURCHASE PARKWAY	Structure	50		Low	0	0
Marshall	JC 9003	45.024	079B00012	JACKSON PURCHASE PARKWAY	Structure	40		Low	0	0
Marshall	JC 9003	40.059	079B00073	JACKSON PURCHASE PARKWAY	Structure	40		Low	0	0
Marshall	JC 9003	42.012	079B00103	Purchase Parkway	Structure	40		Low	0	0
Marshall	JC 9003	48.979	079B00050	JACKSON PURCHASE PARKWAY	Structure	40		Low	0	0
Marshall	JC 9003	0.346	079B00126	Jullian Carroll Parkway	Structure	40		Low	0	0

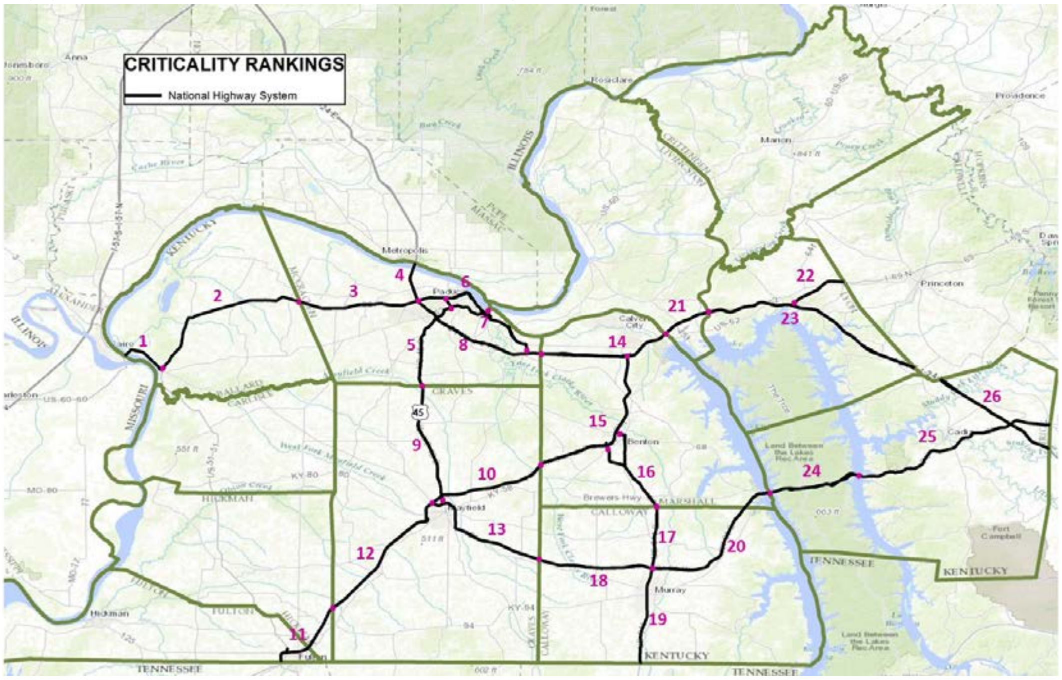
Marshall	JC 9003	51.416	079B00114	ACKSON PURCHASE PARKWAY	Structure	40		Low	0	0
Marshall	KY 348	7.513	079B00102	JACKSON PURCHASE PARKWAY	Structure	40		Low	0	0
Marshall	KY 80	0.696	079B00147	OVER COOL CREEK	Culvert	40		Low	0	1
Marshall	US 641	2.017	079B00121	MYERS CREEK	Culvert	40		Low	0	0
Marshall	US 641	5.91	079B00026	FORK OF OLD BEE CREEK	Culvert	40		Low	0	1
Marshall	US 641	7.981	079B00099	TOWN CREEK	Bridge	40		Low	0	1
Marshall	US 641	7.953	079B00148	TOWN CREEK	Bridge	40		Low	0	1
Marshall	US 641	0.243	079B00120	WADES CREEK	Bridge	40		Low	0	1
Marshall	US 641S	3.25	079B00144	Jullian M. Carroll PW	Structure	40		Low	0	0
Marshall	US 68	9.435	079B00001	JACKSON PURCHASE PARKWAY	Structure	40		Low	0	0
McCracken	I 24	11.441	073B00117	BEE BR OF ISLAND CRK.	Culvert	60		Low	0	0
McCracken	I 24	13.355	073B00120	CLARKS RIVER	Bridge	50		Low	0	1
McCracken	I 24	4.592	073B00107	PERKINS CREEK CHANNEL CH	Bridge	60		Low	0	1
McCracken	I 24	10.34	073B00115	ISLAND CREEK	Bridge	60		Low	0	1
McCracken	I 24	0.435	073B00100	OHIO RIVER	Bridge	60		Low	0	1
McCracken	I 24	11.059	073B00116	KY 1954 (HUSBAND RD)	Structure	60		Low	0	0
McCracken	I 24	2.959	073B00102	KY 305	Structure	60		Low	0	0
McCracken	I 24	11.997	073B00118	OLD L & N RR BED	Structure	60		Low	0	0
McCracken	I 24	8.616	073B00122	I-24	Structure	60		Low	0	0
McCracken	I 24	12.648	073B00119	KY. 450 (OAKS ROAD)	Structure	50		Low	0	0
McCracken	I 24	3.41	073B00103	P&L RAILWAY	Structure	60		Low	0	0
McCracken	I 24	3.723	073B00104	P&L RAILWAY	Structure	60		Low	0	0
McCracken	I 24	14.101	073B00065	I-24 @ 14.09	Structure	50		Low	0	0

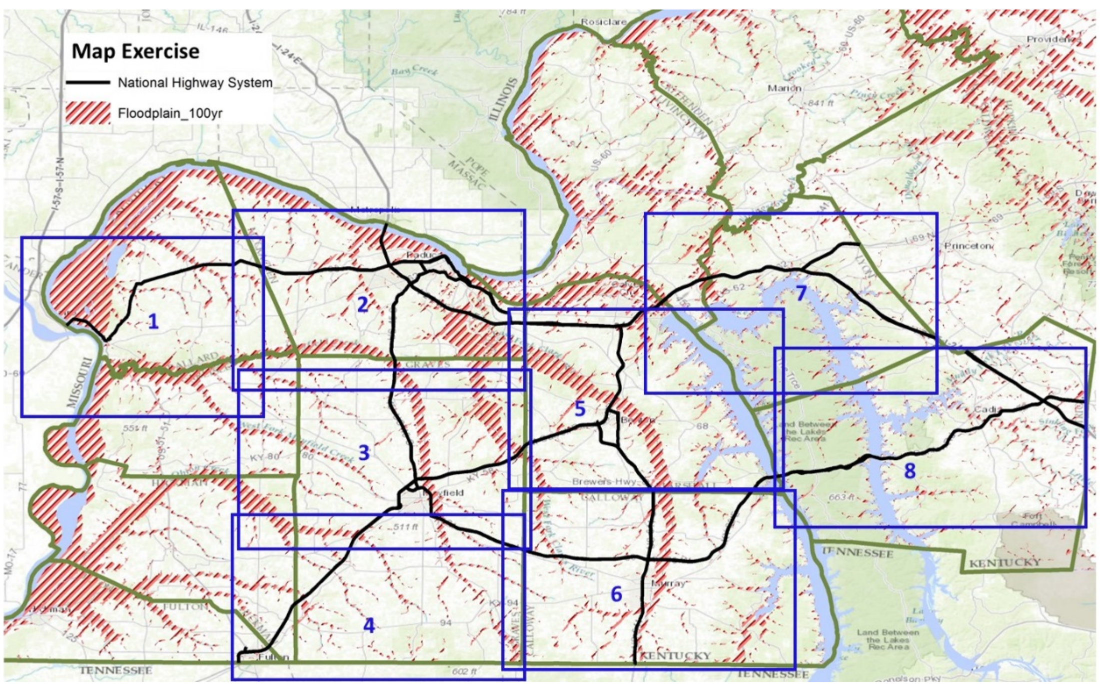
McCracken	I 24	9.816	073B00114	P&L RR-POOL RD- CR 5034G	Structure	60		Low	0	0
McCracken	I 24	2.285	073B00101	KY 1420	Structure	60		Low	0	0
McCracken	I 24	5.599	073B00111	BUCHNER LANE	Structure	60		Low	0	0
McCracken	I 24	15.769	073B00009	I 24	Structure	50		Low	0	0
McCracken	I 24	16.883	073B00064	I-24	Structure	50		Low	0	0
McCracken	I 24	7.364	073B00113	I-24 @ ELMDALE ROAD	Structure	60		Low	0	0
McCracken	US 45	8.023	073B00112	U.S. 45	Structure	60		Low	0	0
McCracken	US 45	9.629	073R00600	US-45	Structure	60		Low	0	0
McCracken	US 60	4.883	073B00162	UNNAMED STREAM	Culvert	80		Low	0	1
McCracken	US 60	12.705	073B00135	Perkins Creek	Culvert	60		Low	0	1
McCracken	US 60	7.669	073B00155	BLACKS BRANCH	Culvert	60		Low	0	1
McCracken	US 60	4.391	073B00159	W. Fork Massac Creek	Bridge	80		Low	0	1
McCracken	US 60	4.615	073B00161	W. FR. MASSAC CR OV. FLO	Bridge	80		Low	0	1
McCracken	US 60	4.467	073B00160	W. FR. MASSAC CR OVER FL	Bridge	80		Low	0	1
McCracken	US 60	8.03	073B00156	W.Fork Massac overflow	Bridge	60		Low	0	1
McCracken	US 60	8.209	073B00164	OVER W. FORK MASSAC CR	Bridge	60		Low	0	1
McCracken	US 60	10.942	073B00106	PERKINS CREEK CHANNEL CH	Bridge	60		Low	0	1
McCracken	US 60	18.625	073B00005	CLARKS RIVER	Bridge	50		Low	0	1
McCracken	US 60	8.322	073B00165	OVER MASSAC CR. OVERFLOW	Bridge	60		Low	0	1
McCracken	US 60	15.626	073B00095	ISLAND CREEK	Bridge	60		Low	0	1
McCracken	US 60	18.625	073B00128	CLARKS RIVER	Bridge	50		Low	0	1
McCracken	US 60	14.523	073B00093	P&L RAILWAY & CLEVELND S	Structure	60		Low	0	0
McCracken	US 60	6.652	073B00154	IC RAILROAD	Structure	60		Low	0	0
McCracken	US 60	19.58	073B00061	P&L RAILWAY	Structure	50		Low	0	0

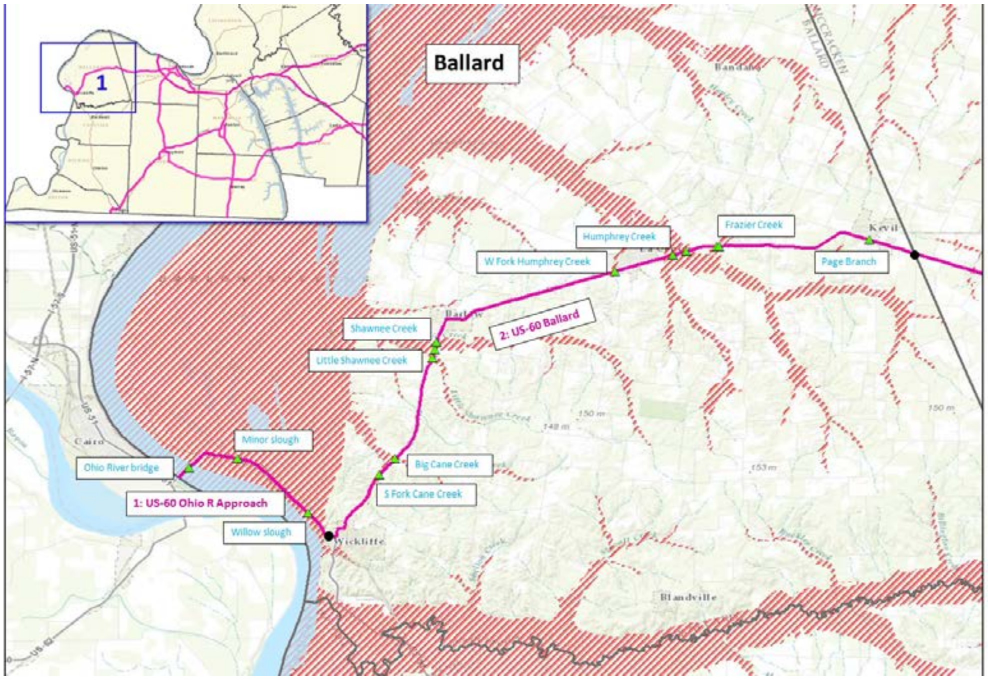
McCracken	US 60	14.871	073B00094	P&L RAILWAY & CALDWELL A	Structure	60		Low	0	0
McCracken	US 60	10.688	073B00105	US 60	Structure	60		Low	0	0
McCracken	US 60	19.5	073B00059	US 62	Structure	50		Low	0	0
McCracken	US 60	11.618	073B00124	P&L RAILWAY	Structure	60		Low	0	0
McCracken	US 60	19.487	073B00062	P&L RAILWAY	Structure	50		Low	0	0
McCracken	US 60X	3.065	073B00130	ISLAND CREEK	Culvert	60		Low	0	0
McCracken	US 62	14.148	073B00063	GARRISON CRK	Culvert	50		Low	0	1
McCracken	US 62	11.837	073B00121	I-24	Structure	60		Low	0	0
McCracken	US 62	13.257	073B00008	US 62	Structure	50		Low	0	0
McCracken	US 68	1.01	073B00060	I-24	Structure	50		Low	0	0
Trigg	I 24	60.297	111B00048	MUDDY FORK CREEK	Bridge	30	Major	Low	0	1
Trigg	I 24	63.905	111B00045	I-24 @.MP. 063.951	Structure	20	Major	Low	0	0
Trigg	I 24	60.493	111B00049	I-24 @.MP. 060.499	Structure	30	Major	Low	0	0
Trigg	I 24	66.527	111B00027	TRW RAILROAD	Structure	20	Major	Low	0	0
Trigg	I 24	67.084	111B00043	I 24	Structure	20	Major	Low	0	0
Trigg	I 24	59.222	111B00047	I-24 @ M.P.59.247	Structure	30	Major	Low	0	0
Trigg	I 24	62.091	111B00050	I-24 @ MP 062.110	Structure	30	Major	Low	0	0
Trigg	US 68	5.672	111B00064	GILBERT CREEK	Culvert	30	Major	Low	0	1
Trigg	US 68	17.937	111B00057	CANEY CREEK	Bridge	30	Major	Low	0	1
Trigg	US 68	5.713	111B00062	ELBOW CREEK	Bridge	30	Major	Low	0	1
Trigg	US 68	7.156	111B00065	Elbow Bay	Bridge	30	Major	Low	0	1
Trigg	US 68	19.142	111B00058	LITTLE RIVER	Bridge	30	Major	Low	0	1
Trigg	US 68	6.215	111B00063	ELBOW CREEK	Bridge	30	Major	Low	0	1
Trigg	US 68	8.588	111B00020	LAKE BARKLEY	Bridge	30	Major	Low	0	1

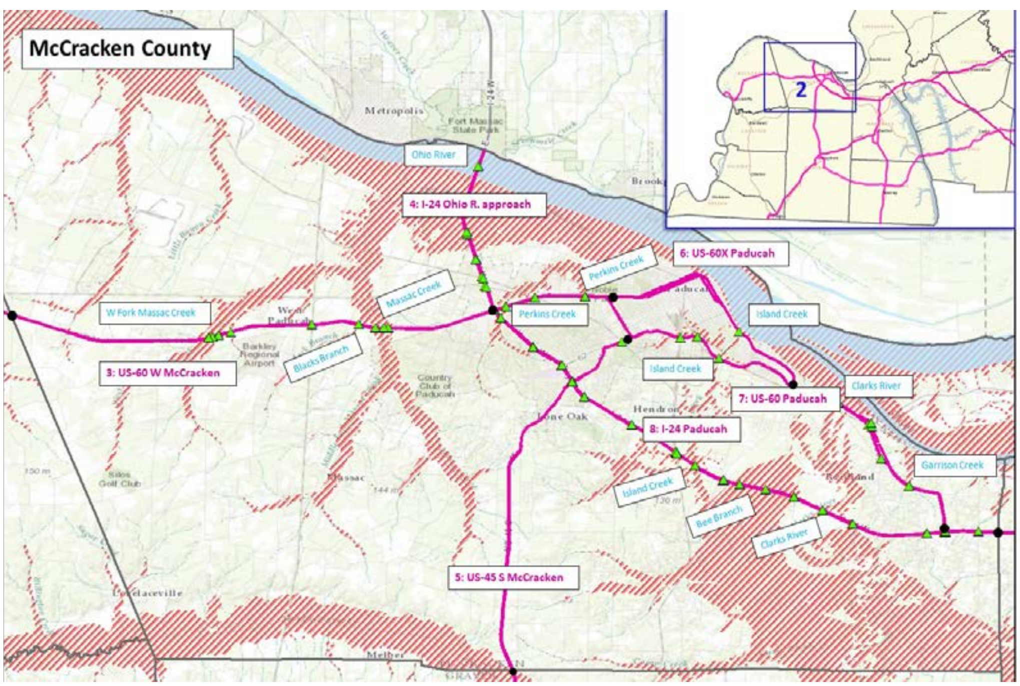
Trigg	US 68	10.958	111B00021	HOPSON CREEK	Bridge	30	Major	Low	0	1
Trigg	US 68	3.101	111B00061	KY-453	Bridge	30		Low	0	0
Trigg	US 68	0.165	079B00023	TENNESSEE RIVER	Bridge	30		Low	0	1
Trigg	US 68	24.414	111B00044	US 68	Structure	20	Major	Low	0	0

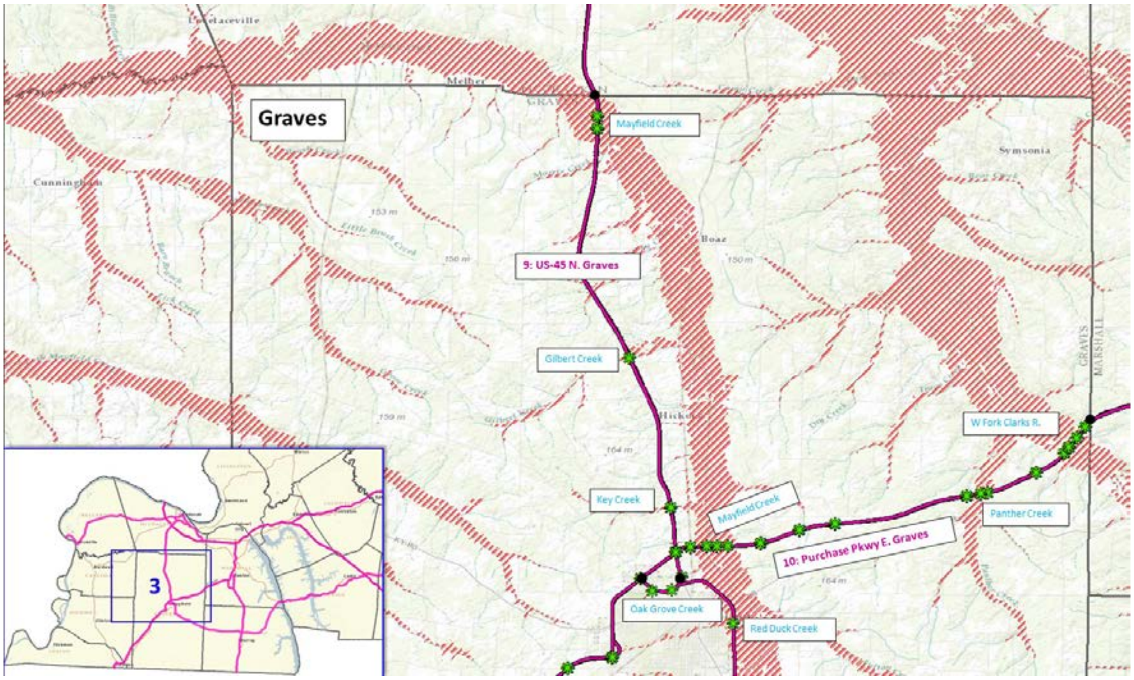
Appendix B: District 1 Meeting Materials

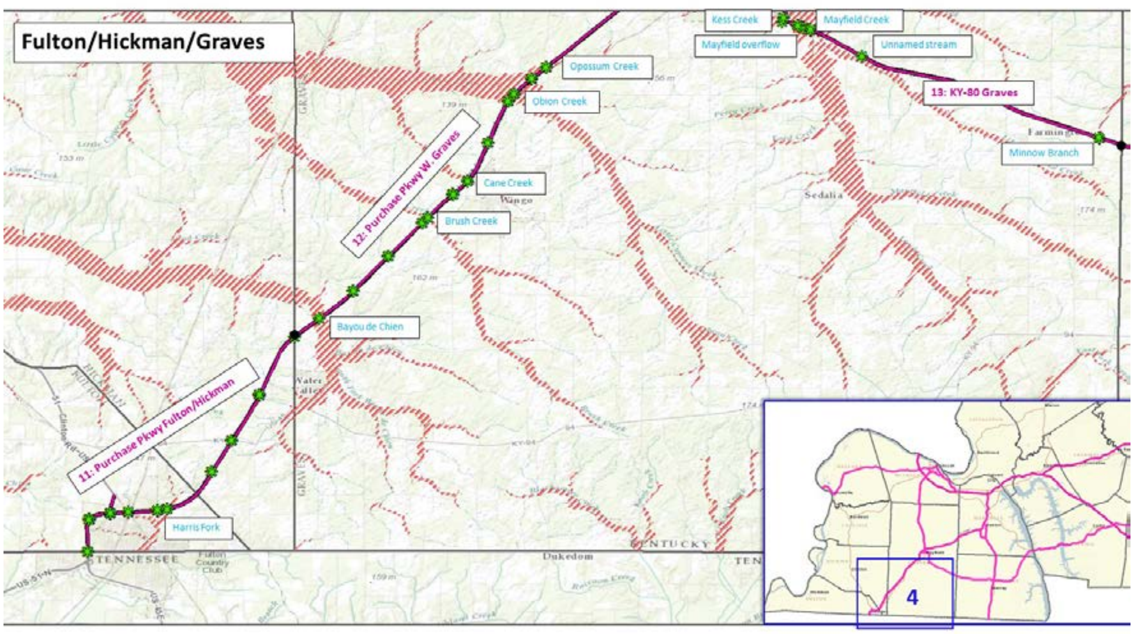


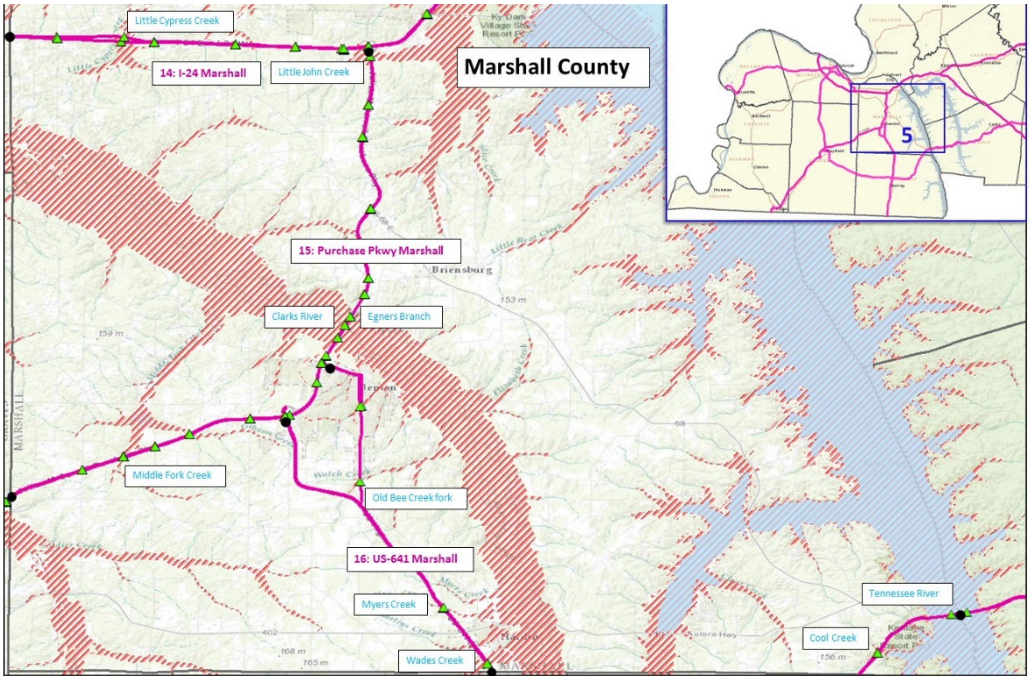


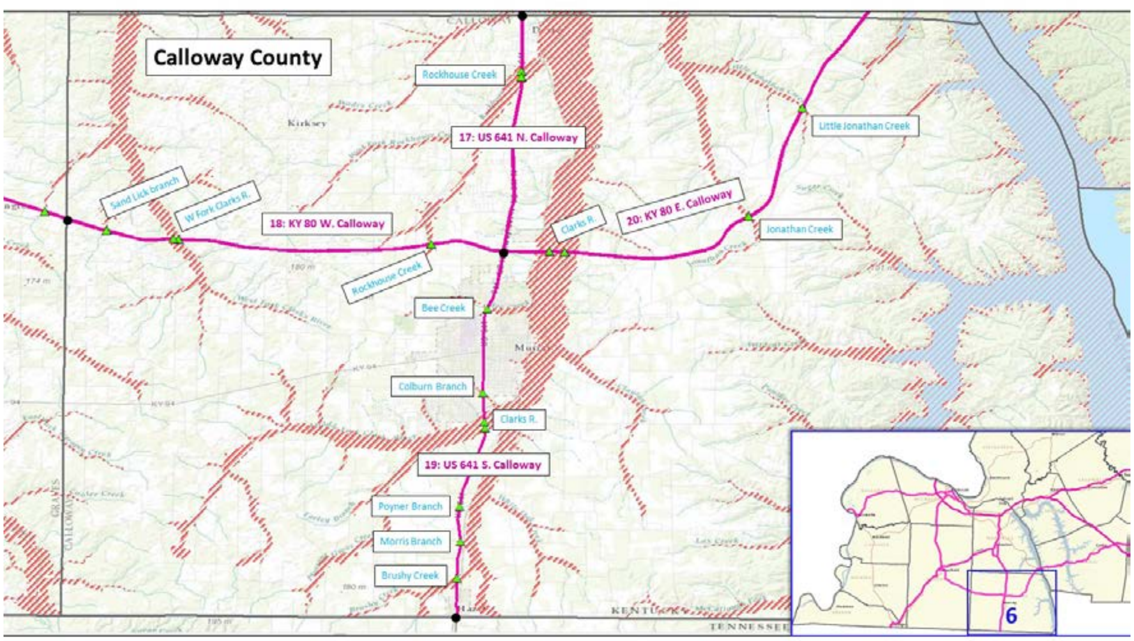

Ballard
1
Humphrey Creek
Frazier Creek
W Fork Humphrey Creek
Page Branch
Kevil
Shawnee Creek
2: US-60 Ballard
Little Shawnee Creek
Minor slough
Big Cane Creek
Ohio River bridge
S Fork Cane Creek
1: US-60 Ohio R Approach
Willow slough
Wickliffe
Blandville

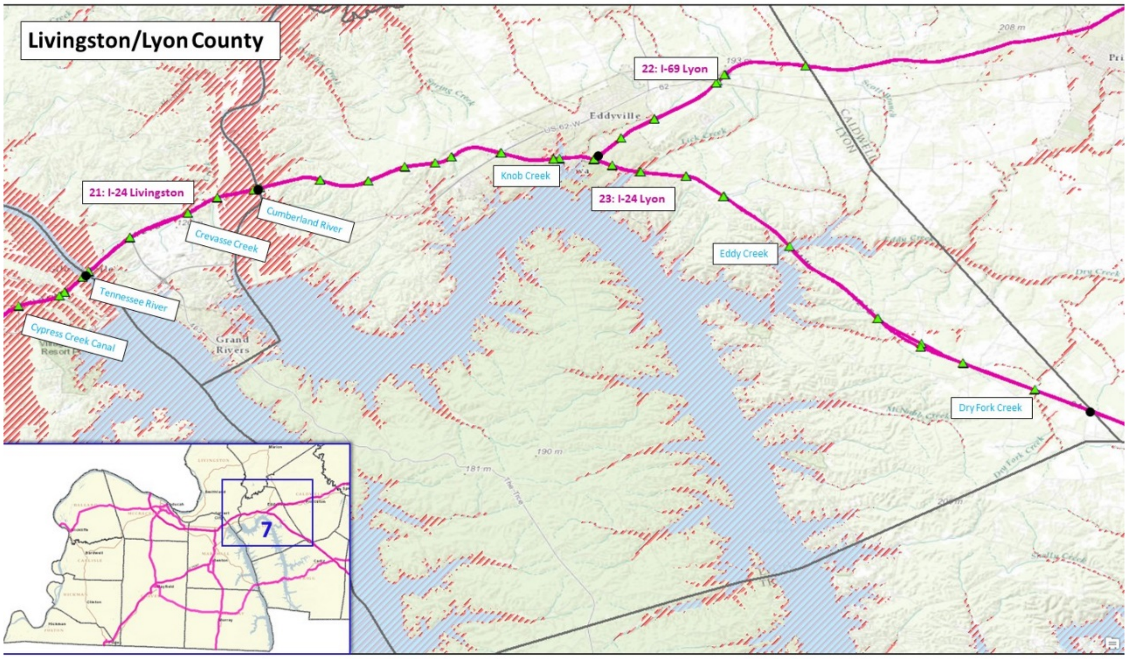

McCracken County
2
Metropolis
Fort Massac State Park
Ohio River
4: I-24 Ohio R. approach
6: US-60X Paducah
Perkins Creek
W Fork Massac Creek
Massac Creek
Perkins Creek
Island Creek
3: US-60 W McCracken
Blacks Branch
Barkley Regional Airport
Island Creek
Clarks River
7: US-60 Paducah
8: I-24 Paducah
Lone Oak
Country Club of Paducah
Garrison Creek
Island Creek
Bee Branch
Clarks River
5: US-45 S McCracken

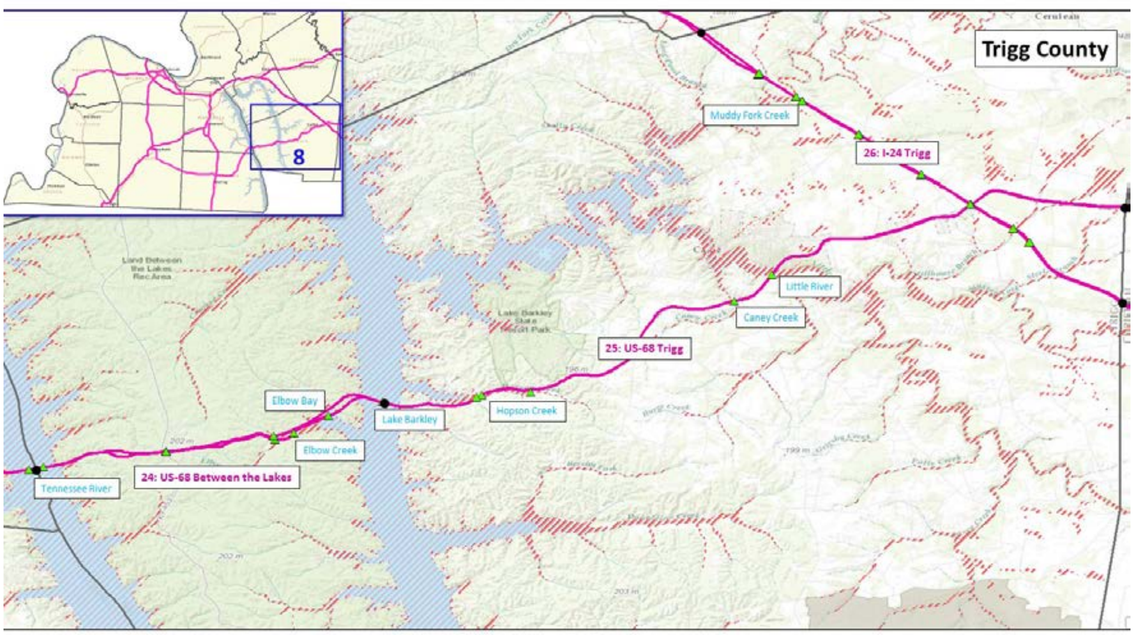

Graves
Mayfield Creek
9: US-45 N. Graves
Gilbert Creek
Key Creek
Mayfield Creek
10: Purchase Pkwy E. Graves
W Fork Clarks R.
Panther Creek
Oak Grove Creek
Red Duck Creek
3
Symsonia
Cunningham
Boaz
GRAVES
MARSHALL


Fulton/Hickman/Graves
Kess Creek
Mayfield Creek
Mayfield overflow
Unnamed stream
13: KY-80 Graves
Opossum Creek
Obion Creek
Minnow Branch
12: Purchase Pkwy W. Graves
Cane Creek
Brush Creek
Sedalia
Bayou de Chien
11: Purchase Pkwy Fulton/Hickman
Harris Fork
TENNESSEE
KENTUCKY
Dukedom
4


Marshall County
Little Cypress Creek
14: I-24 Marshall
Little John Creek
15: Purchase Pkwy Marshall
Clarks River
Egners Branch
Middle Fork Creek
Old Bee Creek fork
16: US-641 Marshall
Myers Creek
Wades Creek
Tennessee River
Cool Creek
Briensburg
5


Calloway County
Rockhouse Creek
Kirksey
17: US 641 N. Calloway
Little Jonathan Creek
Sand Lick branch
W Fork Clarks R.
18: KY 80 W. Calloway
Clarks R.
20: KY 80 E. Calloway
Jonathan Creek
Rockhouse Creek
Bee Creek
Colburn Branch
Clarks R.
19: US 641 S. Calloway
Poyner Branch
Morris Branch
Brushy Creek
6


Livingston/Lyon County
22: I-69 Lyon
21: I-24 Livingston
23: I-24 Lyon
Knob Creek
Cumberland River
Crevasse Creek
Tennessee River
Cypress Creek Canal
Eddy Creek
Dry Fork Creek
Eddyville
Grand Rivers
7


Trigg County
Muddy Fork Creek
26: I-24 Trigg
Little River
Caney Creek
25: US-68 Trigg
Elbow Bay
Lake Barkley
Hopson Creek
Elbow Creek
Tennessee River
24: US-68 Between the Lakes
Land Between the Lakes Rec Area
Cerulean
8

Appendix C: KGS Documented Landslides, KYTC Highway District 1 NHS

Landslide data obtained from the KGS Landslide Inventory database.[93] Images obtained from Google Maps and Google Street View.

1. McCracken County I-24 MP 4.4

SourceDesc: KYTC
SourceID: L-012-1994
County: McCracken
Quad_name_75: Paducah West
GQNumber: 557
Latitude83: 37.07767
Longitude83: -88.680485
Route: I 24
DateObserved: n/a
FailureDate: n/a
FailureYear: n/a
General_Type: n/a
FieldChecked: n/a
Material: n/a
Failure_Type: n/a
Track_Length (ft): n/a
Width (ft): n/a
Head_Scarp_Height (ft): n/a
Slip_Surface_Depth (ft): n/a
Dimensions (ft): n/a
GeologicUnit: Loess
FMCode: 112LOSS
Lithology: n/a
Surficial_Geology: n/a
Geomorphic_Position: n/a
Geomorphic_Shape: n/a
Failure_Location: n/a
Slope_Angle: n/a
Aspect: n/a
Fractures: n/a
Faults: n/a
Water_Present: n/a
Contributing_Factor: n/a
Soil_Type: n/a
Movement_Rate: n/a
Damage: n/a
near_milepoint: n/a
quadrangle_name_1d: Paducah
ADD_District: Purchase
begin_mp: 4
end_mp: 5

[93] KGS, "Landslide Information Map."

2. McCracken County US 60 MP 11.6

SourceDesc: KYTC
SourceID: L-008-1979
County: McCracken
Quad_name_75: Paducah West
GQNumber: 557
Latitude83: 37.082862
Longitude83: -88.666018
Route: US 60
DateObserved: 8/15/1979
FailureDate: n/a
FailureYear: n/a
General_Type: n/a
FieldChecked: n/a
Material: earth
Failure_Type: n/a
Track_Length (ft): n/a
Width (ft): n/a
Head_Scarp_Height (ft): n/a
Slip_Surface_Depth (ft): n/a
Dimensions (ft): n/a
GeologicUnit: Porters Creek Clay
FMCode: 125PRCK
Lithology: Clay and sand
Surficial_Geology: n/a
Geomorphic_Position: n/a
Geomorphic_Shape: n/a
Failure_Location: general road embankment
Slope_Angle: n/a
Aspect: n/a
Fractures: n/a
Faults: n/a
Water_Present: n/a
Contributing_Factor: n/a
Soil_Type: clay loam, silty clay loam, clay, and silty clay (different stations)
Movement_Rate: n/a
Damage: n/a
near_milepoint: n/a
quadrangle_name_1d: Paducah
ADD_District: Purchase
begin_mp: 10
end_mp: 11

3. McCracken County I-24 MP 6.8

SourceDesc: KYTC
SourceID: L-006-1992
County: McCracken
Quad_name_75: Paducah West
GQNumber: 557
Latitude83: 37.052399
Longitude83: -88.651457
Route: I 24
DateObserved: n/a
FailureDate: n/a
FailureYear: n/a
General_Type: n/a
FieldChecked: n/a
Material: n/a
Failure_Type: n/a
Track_Length (ft): n/a
Width (ft): n/a
Head_Scarp_Height (ft): n/a
Slip_Surface_Depth (ft): n/a
Dimensions (ft): n/a
GeologicUnit: Loess
FMCode: 112LOSS
Lithology: n/a
Surficial_Geology: n/a
Geomorphic_Position: n/a
Geomorphic_Shape: n/a
Failure_Location: n/a
Slope_Angle: n/a
Aspect: n/a
Fractures: n/a
Faults: n/a
Water_Present: n/a
Contributing_Factor: n/a
Soil_Type: n/a
Movement_Rate: n/a
Damage: n/a
near_milepoint: n/a
quadrangle_name_1d: Paducah
ADD_District: Purchase
begin_mp: 6
end_mp: 6.8

4. McCracken County I-24 MP 11.05

SourceDesc: KYTC
SourceID: L-006-2009
County: McCracken
Quad_name_75: Paducah East
GQNumber: 531
Latitude83: 37.024729
Longitude83: -88.610536
Route: I 24
DateObserved: n/a
FailureDate: n/a
FailureYear: n/a
General_Type: n/a
FieldChecked: n/a
Material: n/a
Failure_Type: n/a
Track_Length (ft): n/a
Width (ft): n/a
Head_Scarp_Height (ft): n/a
Slip_Surface_Depth (ft): n/a
Dimensions (ft): n/a
GeologicUnit: Artificial fill
FMCode: 111FILL
Lithology: n/a
Surficial_Geology: n/a
Geomorphic_Position: n/a
Geomorphic_Shape: n/a
Failure_Location: n/a
Slope_Angle: n/a
Aspect: n/a
Fractures: n/a
Faults: n/a
Water_Present: n/a
Contributing_Factor: n/a
Soil_Type: n/a
Movement_Rate: n/a
Damage: n/a
near_milepoint: n/a
quadrangle_name_1d: Paducah
ADD_District: Purchase
begin_mp: 9
end_mp: 11

5. Lyon County I-24 MP 41.4

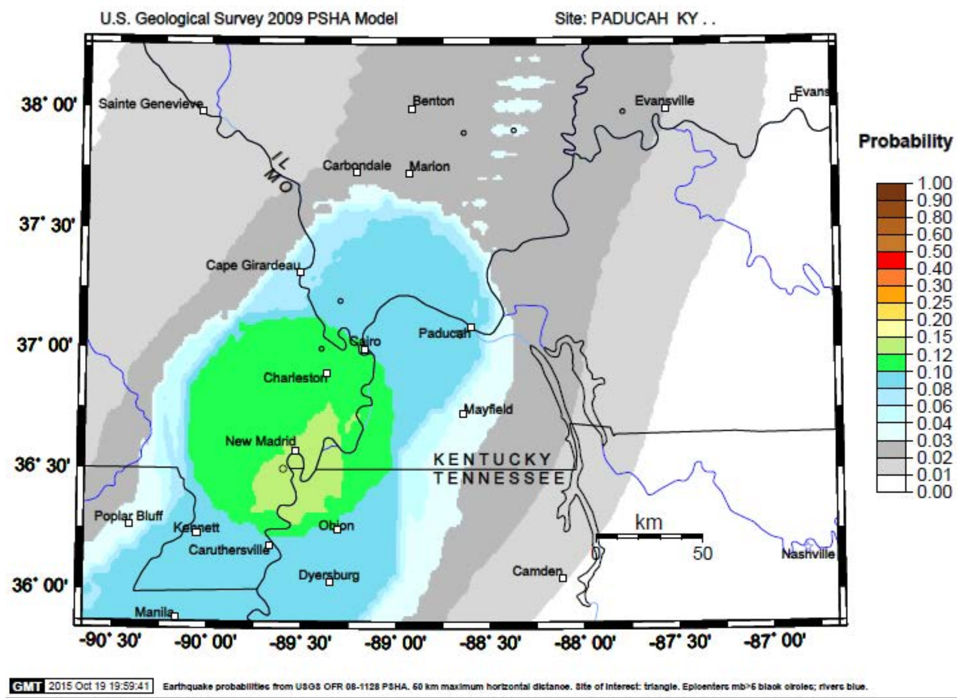
SourceDesc: KYTC
SourceID: L-016-2011
County: Lyon
Quad_name_75: Eddyville
GQNumber: 255
Latitude83: 37.073024
Longitude83: -88.089111
Route: I 24
DateObserved: n/a
FailureDate: n/a
FailureYear: n/a
General_Type: n/a
FieldChecked: n/a
Material: n/a
Failure_Type: n/a
Track_Length (ft): n/a
Width (ft): n/a
Head_Scarp_Height (ft): n/a
Slip_Surface_Depth (ft): n/a
Dimensions (ft): n/a
GeologicUnit: Warsaw Limestone
FMCode: 333WRSW
Lithology: n/a
Surficial_Geology: n/a
Geomorphic_Position: n/a
Geomorphic_Shape: n/a
Failure_Location: n/a
Slope_Angle: n/a
Aspect: n/a
Fractures: n/a
Faults: n/a
Water_Present: n/a
Contributing_Factor: n/a
Soil_Type: n/a
Movement_Rate: n/a
Damage: n/a
near_milepoint: n/a
quadrangle_name_1d: Paducah
ADD_District: Pennyrile
begin_mp: 41.400002
end_mp: n/a

6. Lyon County I-24 MP 41.4

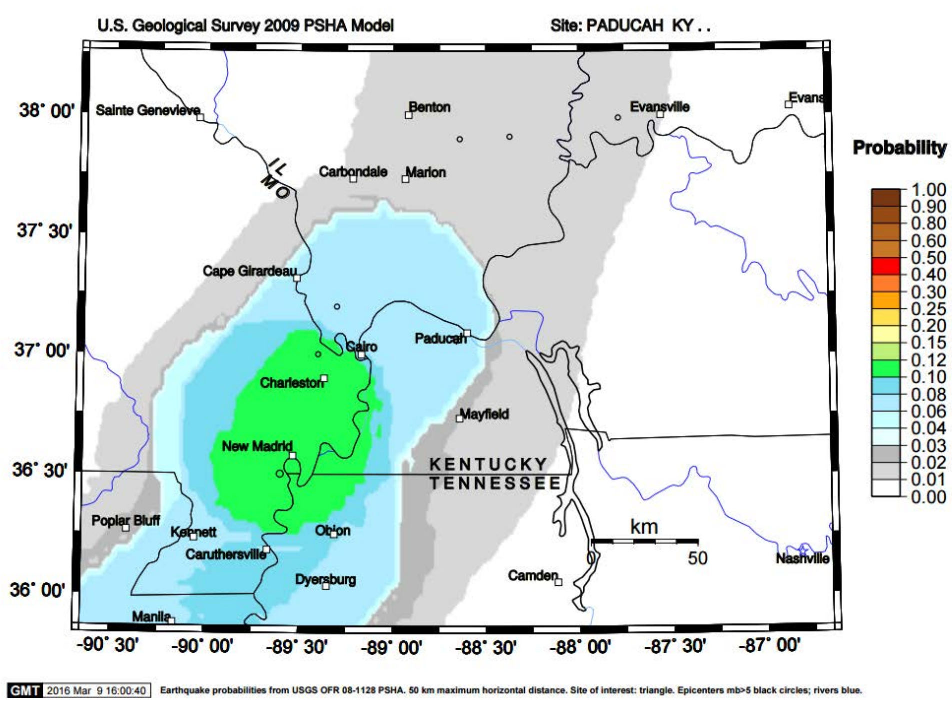
SourceDesc: KYTC
SourceID: L-018-2013
County: Lyon
Quad_name_75: Eddyville
GQNumber: 255
Latitude83: 37.066605
Longitude83: -88.068712
Route: I 24
DateObserved: n/a
FailureDate: n/a
FailureYear: 2013
General_Type: landslide
FieldChecked: n/a
Material: n/a
Failure_Type: n/a
Track_Length (ft): n/a
Width (ft): 300
Head_Scarp_Height (ft): n/a
Slip_Surface_Depth (ft): n/a
Dimensions (ft): n/a
GeologicUnit: Fort Payne Formation
FMCode: 337 PN
Lithology: Siltstone and dolomite
Surficial_Geology: alluvium
Geomorphic_Position: n/a
Geomorphic_Shape: n/a
Failure_Location: n/a
Slope_Angle: n/a
Aspect: n/a
Fractures: n/a
Faults: yes
Water_Present: n/a
Contributing_Factor: n/a
Soil_Type: n/a
Movement_Rate: n/a
Damage: yes
near_milepoint: 42.6
quadrangle_name_1d: Paducah
ADD_District: Pennyrile
begin_mp: 42.5
end_mp: 42.700001

Appendix D. Seismic Probability Maps for District 1

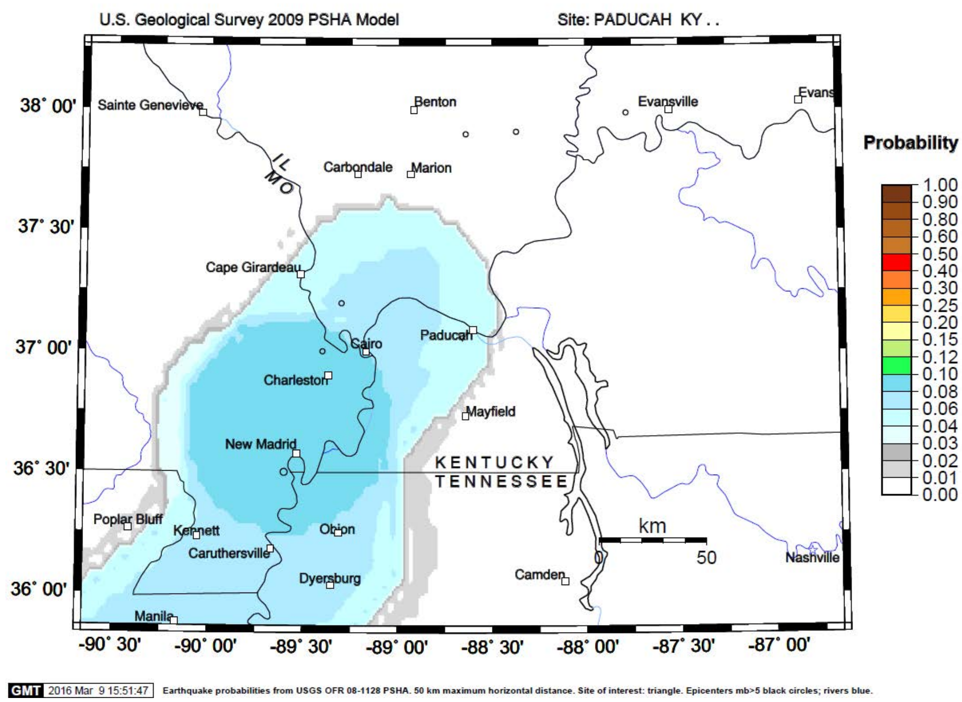
Probability of earthquake with M > 5.5 within 35 years & 50 km



Probability of earthquake with M > 6.0 within 35 years & 50 km



Probability of earthquake with M > 7.0 within 35 years & 50 km



Appendix E: Tornadoes in District 1, 1950-2014.

Since 1950, two EF4 tornadoes have impacted District 1, the most recent in 1968. In 2013 an EF3 tornado ripped through Paducah, KY and Brookport, IL killing 3 people and injuring dozens more along its 42-mile-long path.