KENTUCKY TRANSPORTATION CABINET TRANSPORTATION RESILIENCE IMPROVEMENT PLAN

JULY 2023

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1. INTRODUCTION

1.1. OVERVIEW

The Kentucky Transportation Cabinet's (KYTC's) mission is to provide a safe, efficient, environmentally sound, and fiscally responsible transportation system that delivers economic opportunity and enhances the quality of life in Kentucky. Transportation resilience, defined by the Federal Highway Administration (FHWA) as the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions, is an important component of KYTC's mission. Resilience involves planning, designing, maintaining, and repairing transportation infrastructure to better prepare for climate impacts and natural disasters.

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

Recent events in Kentucky have demonstrated the devastating power of extreme weather events. In December 2021 western Kentucky was struck by a severe tornado outbreak that killed eighty people and resulted in damages estimated to total upward of four billion dollars. Over fifteen thousand homes and businesses throughout the region were destroyed or badly damaged. Cities such as Mayfield, Princeton, and Dawson Springs suffered catastrophic damage.

Source: National Weather Service Storm Survey.

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

These events are part of a larger trend of increased frequency of extreme weather events that are wreaking havoc on Kentucky communities and straining public agency budgets. These events pose a significant threat to the safety, reliability, effectiveness, and sustainability of transportation infrastructure and operations.

The Kentucky Transportation Cabinet is prepared to respond to impacts of weather events, natural disasters and changing conditions through coordination with other agencies, mitigation strategies, preparedness, and response and recovery efforts. KYTC is a first response partner with Emergency Management and local governments to deploy resources including personnel and equipment during events. KYTC has deep experience with planning and statewide communication including year-round emergency response partner outreach and participation in emergency drills. A description of the agency response roles and responsibilities can be found in the Kentucky Transportation Cabinet All Hazards Response Plan developed by the Division of Incident Management. Weather events also influence strategies and investments in both projects and operations through consideration of resiliency factors and building back with consideration of future risk. Strategies are outlined within the KYTC Transportation Asset Management Plan.

The goal of this Resilience Improvement Plan is to better place Kentucky to prepare for, respond to, and withstand future extreme weather and natural hazard events affecting the transportation system. This Plan involves a risk-based assessment that factors the likelihood of the event, the severity of the damages, and the criticality of the transportation assets. Strategies included in this Plan will improve transportation resilience in support of KYTC's overall mission.

1.2. REQUIREMENTS

Transportation Resilience Improvement Plans are not a federal requirement for transportation agencies. However, agencies are encouraged to develop a plan in accordance with 23 U.S.C. Section 176(e) to address surface transportation system resilience to current and future weather events and natural disasters. Agencies that have developed an eligible plan qualify for a lower non-federal match from the FHWA PROTECT Formula Program.

FHWA identifies the following criteria as requirements for an eligible Resilience Improvement Plan:

- The plan should be for the immediate and long-range planning activities and investments of the State.
- Demonstrate a systemic approach across modes, geographic regions, and critical interdependent sectors.
- Include a risk-based assessment of vulnerabilities to weather and natural disasters, such as severe storms, flooding, drought, levee and dam failures, wildfire, rockslides, mudslides, sea level rise, extreme weather (including extreme temperatures), and earthquakes. The risk-based assessment should consider both the probability of assets being affected by future weather and disasters as well as the consequences of those events.

This Kentucky Resilience Improvement Plan reflects KYTC's efforts to identify vulnerabilities, develop risk-based strategies, and schedule and prioritize improvements. This Plan serves as the summary of agency resiliency efforts and provides strategies for developing a more robust resilience planning program within the agency. The Plan will:

- Provide references for resilience planning and response efforts within other Agency plans.
- Inform Cabinet resiliency policy.
- Guide resilience investment strategy for planning, design, and asset management.
- Outline the resilience research roadmap for the Cabinet.

This Plan will be updated as ongoing and future resilience planning activities are completed including a listing of specific projects.

1.3. COORDINATION WITH OTHER PLANS

The KYTC Resilience Improvement Plan has been developed and will be implemented in coordination with other agency-wide planning efforts. These include:

KYTC Transportation Asset Management Plan (TAMP)

KYTC has made a strong commitment to on-going investments to preserve asset conditions and system performance as cost-effectively as possible. TAMPs serve as a focal point for information about assets, management strategies, long-term expenditure forecasts, and business processes. The KYTC TAMP relies

on asset inventory and condition data to drive performance-based resource allocation and project selection decisions. These results are crucial elements for achieving the Cabinet's mission, vision, and goals and enables KYTC to be accountable to its customers by:

- Minimizing the annual costs of preserving the system.
- Maximizing system performance within budget constraints.
- Supporting an objective, data-driven decision-making process.
- Balancing expectations with available funding.

KYTC has taken a holistic approach to build a more transportation network as demonstrated by the integration of the resilience improvement strategies within the TAMP. This includes consideration of friction design adaption strategies for increased precipitation during the pavement life cycle and prioritization of bridge asset management projects through an index that considers resiliency factors such as scour risk and flood vulnerability.

KYTC Long Range Statewide Transportation Plan (LRSTP)

The LRSTP is a 20+ year multimodal plan for Kentucky's transportation system produced by KYTC and required through federal transportation reauthorization acts. The LRSTP identifies a vision and set of goals developed through outreach and consultation, transportation needs, available resources and the transportation strategies which will be utilized to serve the mobility, safety, and economic needs of the people most efficiently.

The LRST identifies the following planning goals and objectives to mitigate climate change:

- Encourage innovative design and development that is sensitive to the environment
- Preserve environmental integrity or natural, cultural, and physical resources
- Minimize risk to flood hazards
- Ensure a proper relationship between waterways and development
- Promote energy efficiency and conservation
- Protect, enhance, and restore our living environment
- Protect natural beauty
- Provide and enhance the quality of natural and human environmental resources

The LRSTP identifies challenges and vulnerable assets in agreement with the Resiliency Improvement Plan. Transportation consequences are both direct and indirect as the system is considered. The 2022-2045 LRSTP Climate Change Overview references the RIP as the baseline document for guiding resiliency related planning efforts. In addition, the LRSTP references data and methodologies within the RIP for climate trends and consequences.

KYTC Freight Plan

KYTC's goal for freight transportation is to provide a safe, reliable, efficient, and effective transportation system for the movement of passengers and freight within the commonwealth as well as connect

Kentucky to domestic and international markets. KYTC recognizes that an effective multimodal freight system must have resiliency consideration to help improve public safety, alleviate highway congestion, and contribute to economic development. The KYTC Freight Plan leads efforts to

- Document freight assets
- Identify future needs
- Recommend strategic initiatives
- Devise implementation strategies

The Kentucky Freight Plan is a supplement to the LRSTP that works in conjunction with the strategies identified within the Resiliency Improvement Plan.

Commonwealth of Kentucky Enhanced Hazard Mitigation Plan (EHMP)

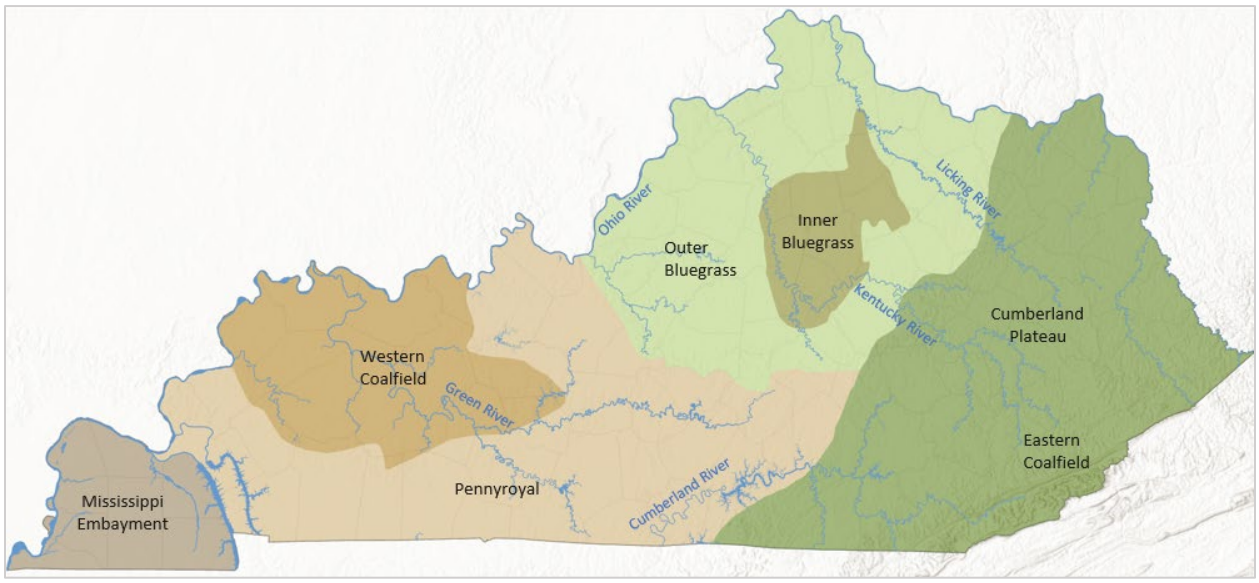
Kentucky is one of fifteen states to have earned FEMA approval for its enhanced hazard mitigation plan. To receive approval of an enhanced plan, a state must show that it has developed a comprehensive mitigation program and can manage increased funding for its mitigation goals. Hazard mitigation planning reduces loss of life and property by minimizing the impact of disasters. It begins with state, tribal, and local governments identifying natural disaster risks and vulnerabilities that are common in their area. Kentucky's EHMP identifies the following hazards in need of mitigation: flooding, dam failure, drought, earthquakes, landslides, karst, mine subsidence, winter storms, wind, extreme temperatures, and wildfire. The EHMP develops long-term strategies for protecting people and property and breaking the cycle of disaster damage and reconstruction. Community infrastructure including buildings, agriculture and population are included within the EHMP and therefore not directly within the RIP, which initially focuses on major transportation assets.

The EHMP hazard identification and repeated loss assessments are based upon data sets and methodologies that agree with methodologies within the Resiliency Improvement Plan. The common analysis and data set across agencies allows the Resiliency Improvement Plan strategies to be applied to local assets through regional planning districts and mitigation programs via coordination with Emergency Management. The EHMP identifies hazards beyond the those identified in the RIP including Dam Hazard Mitigation and Mine Subsidence. This initial RIP provides focus on natural hazards with a higher probability of occurrence and an available data set to assess risk. Mitigation strategies identified agree with the assessments within the RIP.

2. CLIMATE AND GEOLOGIC HAZARDS

Kentucky is centrally located in the southeastern United States 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 fifty inches of precipitation.

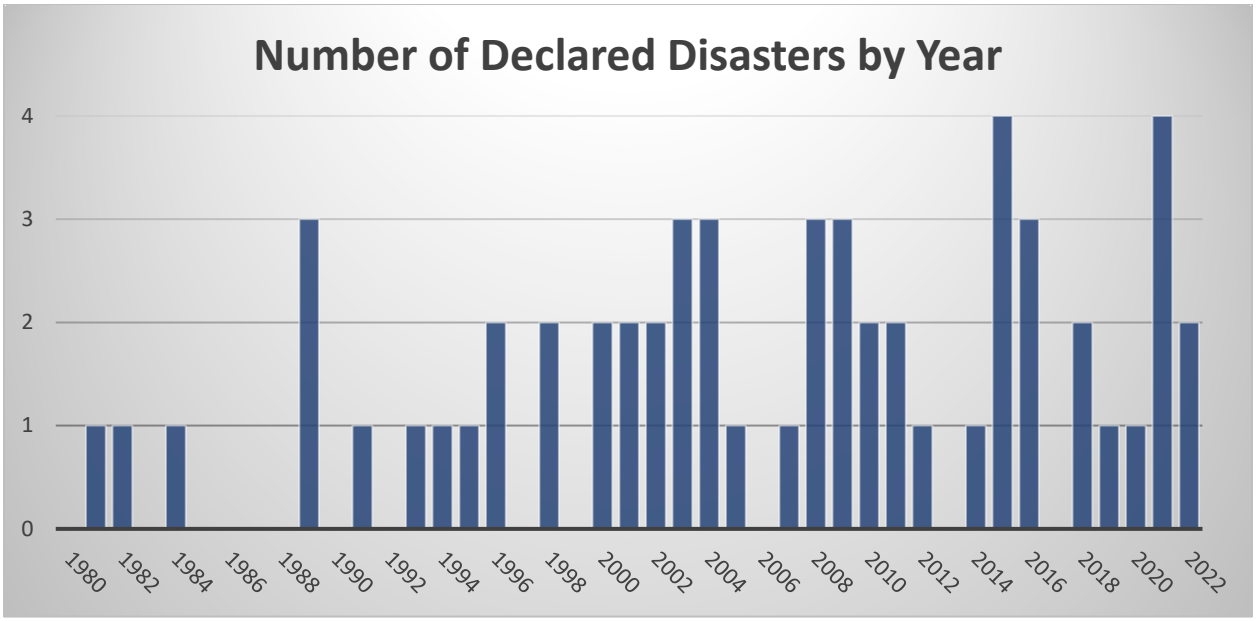
Kentucky's landforms follow a distinct east-west gradient. Elevations are highest and slopes steepest in the east, where the Appalachian Mountains and Cumberland Plateau represent approximately 25 percent of the state's area. The Bluegrass Region, located in the north-central part of the state, includes the three largest urbanized areas of Kentucky. To the south and stretching westward is the Pennyroyal, an area featuring karst landscapes. Adjacent to the Ohio River and encircled by the Mississippian Plateau is the Western Kentucky Coalfield region. Farthest west is the Mississippi Embayment, a low-lying northward extension of the Gulf Coastal Plain. Surface streams generally flow west or northwest in Kentucky, with the Licking River, Kentucky River, Green River, and Cumberland River all being significant tributaries of the Ohio River.



The frequency of natural disasters in Kentucky is trending upward, and severe weather is the most common cause of these disasters. Severe weather includes:

- Severe precipitation, which can lead to flooding and slides
- Severe wind, which can involve either tornados or straight-line winds
- Winter storms, the most damaging of which are ice storms
- Severe heat

From 1980 to 1999, Kentucky averaged 0.7 presidentially declared disasters per year. Since 2000, that average has increased to 1.9 declared disasters per year.



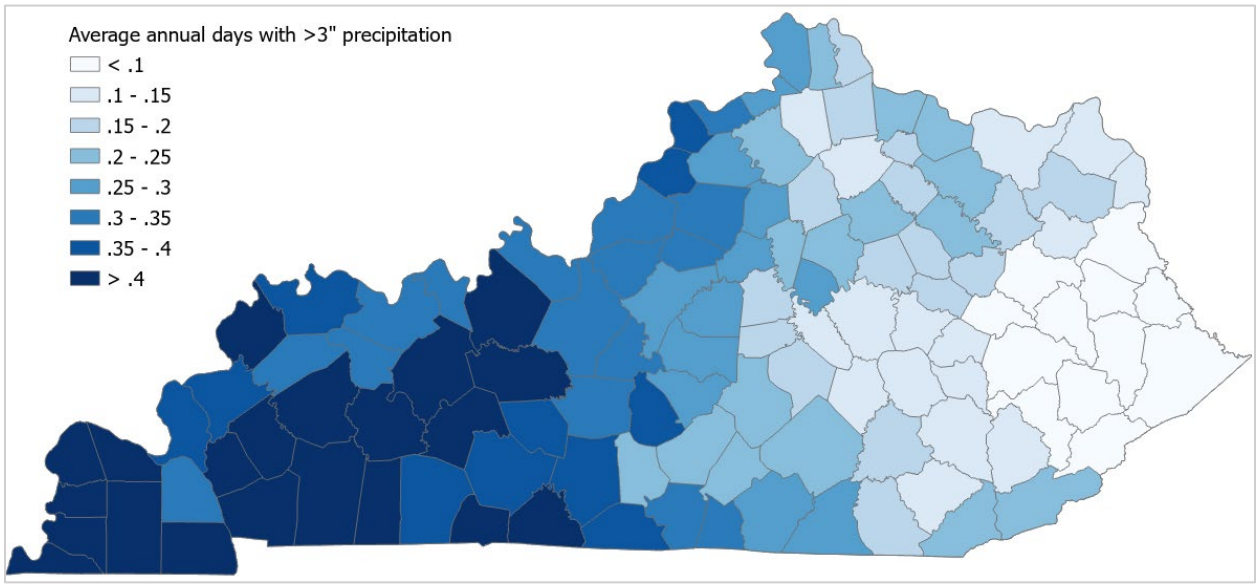
2.1. FLOOD

Flooding is the most common and costly natural hazard encountered in Kentucky, with average annual losses of $40 million. Kentucky has 90,000 miles of streams in the state, making it particularly vulnerable to flooding. Floods in Kentucky can be grouped into two types:

- Regional or riverine flooding results from heavy and persistent rainfall, sometimes coupled with melting snow, which saturates the soil and causes river basins to fill too quickly and with too much water. The nature of riverine flooding can differ depending on the topography. Flooding on the Ohio River and Mississippi River, which encompass large drainage areas across the central United States, tends to occur slowly but also be long lasting. Flooding on upper stretches of the Kentucky River and Licking River can occur more quickly and with faster currents, but the duration of the flooding may be shorter.
- Flash flooding results from excessive rainfall in a short amount of time, causing water levels to rapidly rise and torrents of water to flow through and beyond stream channels. Flash flooding can 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 swift currents which can threaten communities and their infrastructure. Flash flooding can also result from dam failure.

Flooding impacts can be destructive to the transportation system in multiple ways. Erosion, subsidence, landslides, mud flows, sinkholes, and washouts can all result from flooding and cause damage to roadways. Bridges can be structurally impacted by water overflow and scour. Operationally, the system can be disrupted by high water, causing mobility and safety concerns.

The map below depicts the average number of days each year with three or more inches of rainfall. There is an evident west-to-east gradient, with the western part of the state more likely to experience heavy rainfall events. Counties in western Kentucky, 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.



2.2. SEVERE STORMS

Kentucky experiences on average twenty tornadoes per year, the majority of which tend to be of low intensity as measured on the Enhanced Fujita (EF) scale. Since 1950, Kentucky has experienced only one EF5 tornado and 20 EF4 tornadoes, including the long track destructive tornado that wrecked western Kentucky communities in December 2021. While tornadoes are recurring and damage from tornadoes can be extensive, their impacts on the transportation system are typically limited and temporary. Damage or destruction of highway signage and signalization are the most common impacts. Debris in the roadway from structures, utilities, and trees may temporarily disrupt traffic.

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

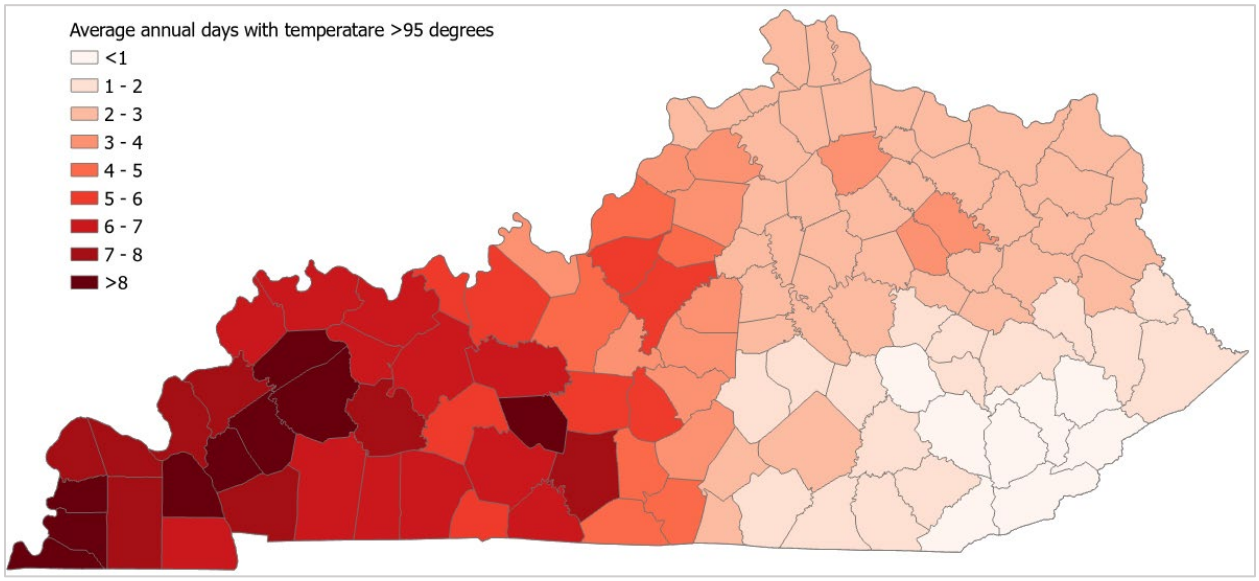
Hail is a type of precipitation that occurs with severe thunderstorms where updrafts of air drive precipitation to higher levels of the atmosphere where it cools, freezes, and then falls as ice. While severe hail can damage vehicles, structures, crops, and livestock, infrastructure damage is limited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

2.3. EXTREME HEAT

The National Weather Service (NWS) defines extreme heat as temperatures 10˚F or more above the average summer high temperature. Heat advisories and warnings are issued when the forecast heat index is expected to exceed such thresholds as above 105˚F for multiple hours or above 115˚F at any point, or when nighttime lows are forecast to be above 80˚F for consecutive days.

Several 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. Extreme heat can also impede highway operations by limiting the availability of construction and maintenance activities.

The spatial pattern of extreme temperatures is similar to the pattern found in the precipitation data. Western parts of the state experience more days where the maximum temperature exceeds 95°F than eastern areas of the state.



2.4. DROUGHT/WILDFIRE

Drought impacts on the transportation system in Kentucky are rare but possible. Roads built in wetland areas are the most vulnerable to prolonged dry conditions. Extreme drought can cause wetlands to dry out, which changes the soil composition and can degrade the underlying roadbed.

Droughts can also lead to wildfires. Most wildfires are attributable to lightning strikes or human activity and are associated with drought conditions, elevated temperatures, and the accumulation of combustible material along a forest floor. Wind also facilitates the spread of fire across the landscape. For the transportation system, wildfire impacts include system delays and recovery costs, such as

maintenance and damage assessment, road repair, guardrails, signage, electrical supply, culverts, and landscaping.

2.5. SEISMICITY

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 human made structures. In certain conditions, earthquakes can trigger other hazards such as landslides and tsunamis. One measure of earthquake magnitude is Peak Ground Acceleration (PGA). PGA measures the Earth's movement at a given location. It accounts for the energy released by an earthquake and how this energy travels through varying types of soil and rock.

In the eastern half of the U.S., the highest threat for seismic activity is the New Madrid seismic zone, which lies near 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. 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.

2.6. LANDSLIDES

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

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

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

2.7. SINKHOLES

Karst topography is associated with sinkholes, caves, sinking streams, and springs. In Kentucky, karst potential is highest in the Inner Bluegrass Region, the Western Pennyroyal region, and the Eastern Pennyroyal region. Kentucky is fifth in the nation in terms of impact from sinkholes. Estimates indicate that 55 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.

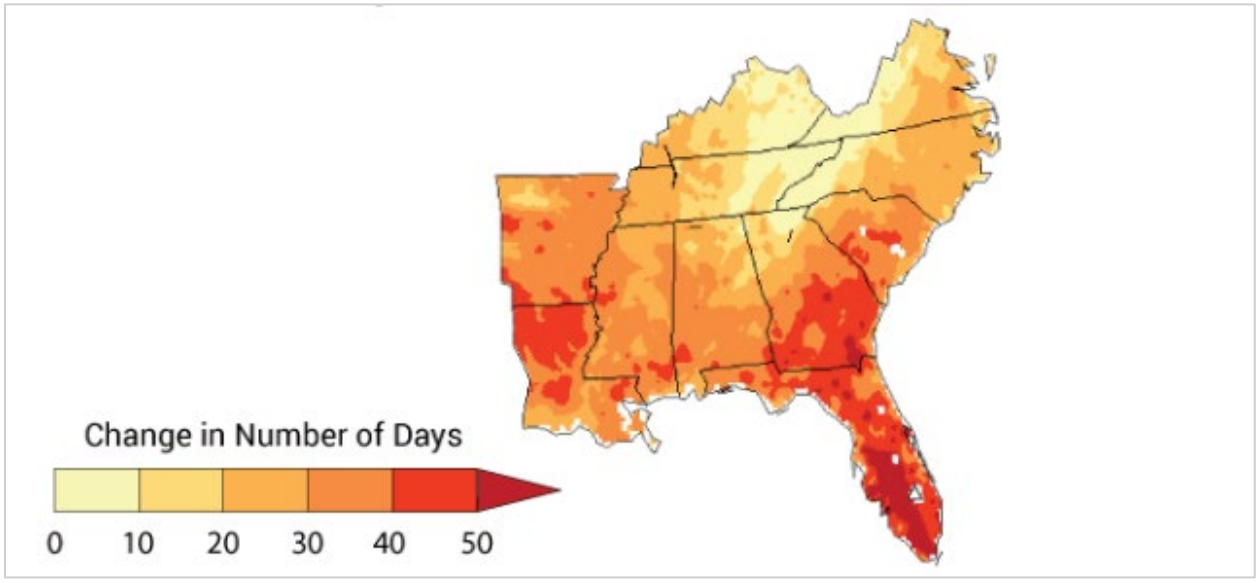
Sinkholes and karst formation can impact highway infrastructure by causing the collapse of roadway surfaces, ditch lines, and bridge foundations. Karst-related flooding can cause temporary road closures, roadway damage, or problems with drainage and rainwater runoff.

2.8. CLIMATE PROJECTIONS

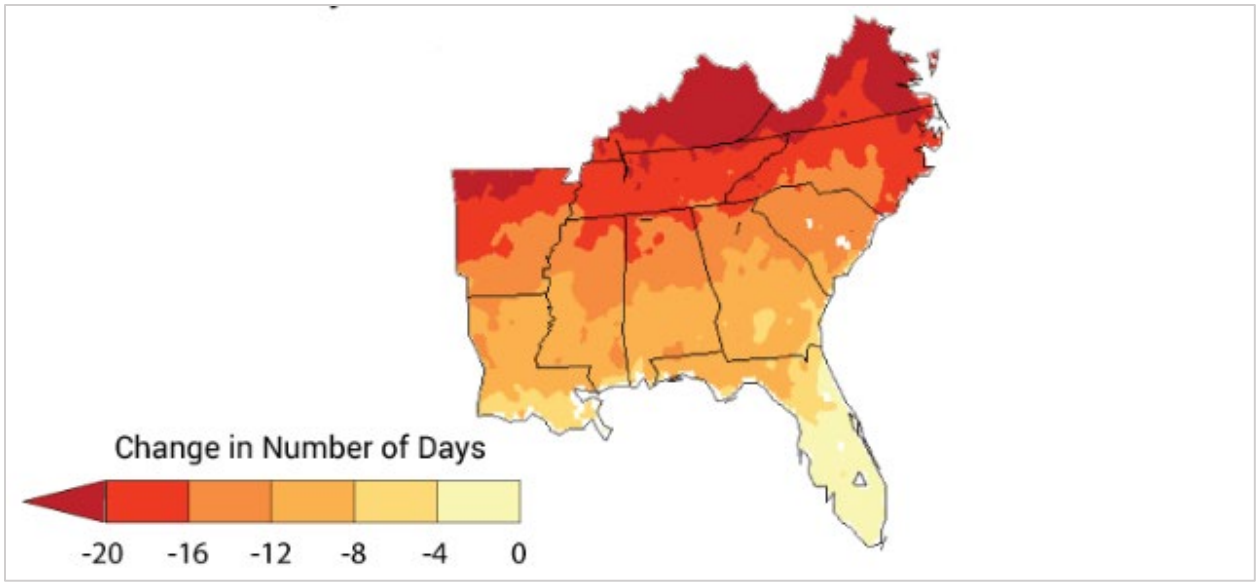
Climate projections provide a useful tool for understanding the frequency with which weather patterns are likely to occur. For transportation planners, this information can help formulate informed decisions regarding mitigation efforts to extreme weather events that may become more severe and occur more frequently in the future.

The Fourth National Climate Assessment (NCA4), published in 2018, includes Kentucky in its southeast assessment region. The NCA4 findings indicate that Kentucky **will gradually warm** during the 21st century:

- Winters will grow milder.
- Extremely hot summer days will become more frequent.
- Higher maximum temperatures during the summer could result in prolonged periods of extreme heat and extended periods of drought.



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 period with respect to the reference period of 1920-2000. Source: NCA4.

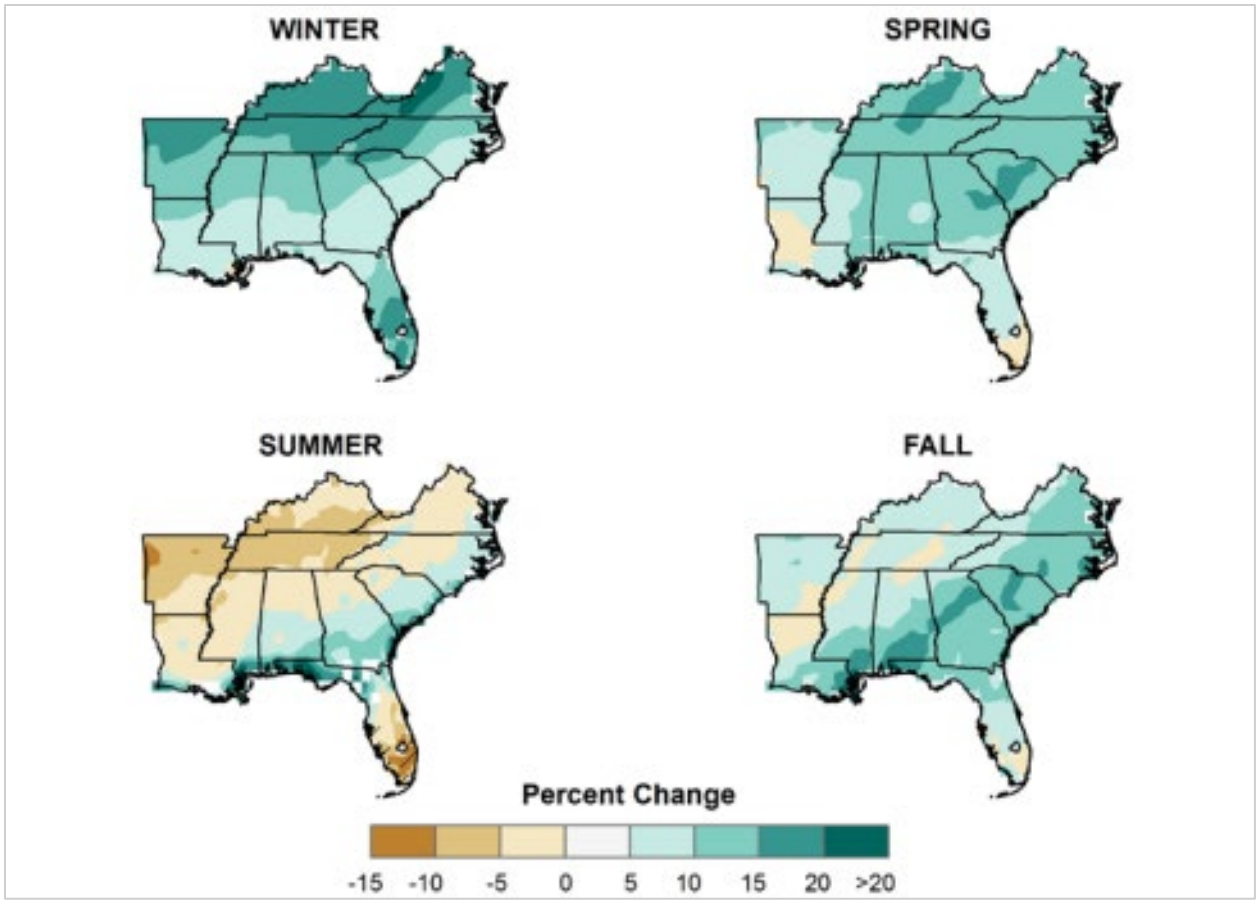


Simulated difference in the mean annual number of days with a minimum temperature lower than 32°F for the Southeast region for the 2041-2070 period with respect to the reference period of 1920-2000. Source: NCA4.

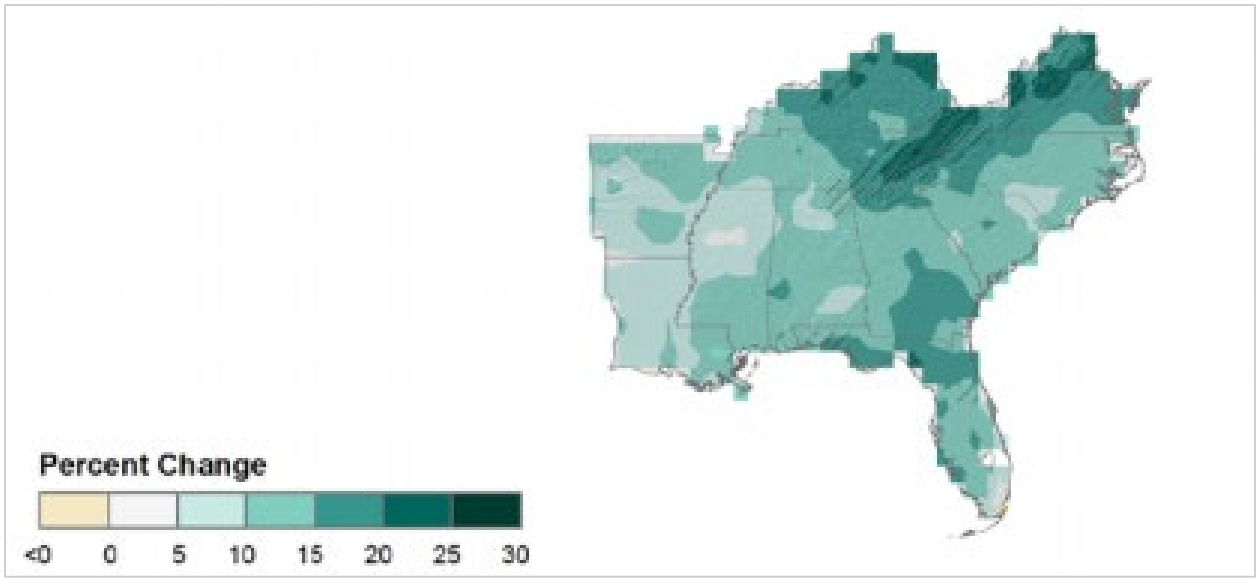
The NCA4 findings also indicate that Kentucky will experience an **increase in annual precipitation**.

- Winter and spring months projected to have the highest increase.
- Summer months may have decreased precipitation.
- Projections also show greater likelihood of heavy precipitation events.

These projections will result in more frequent and severe flooding, while also increasing the likelihood of extreme heat events and drought during the summer months.



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

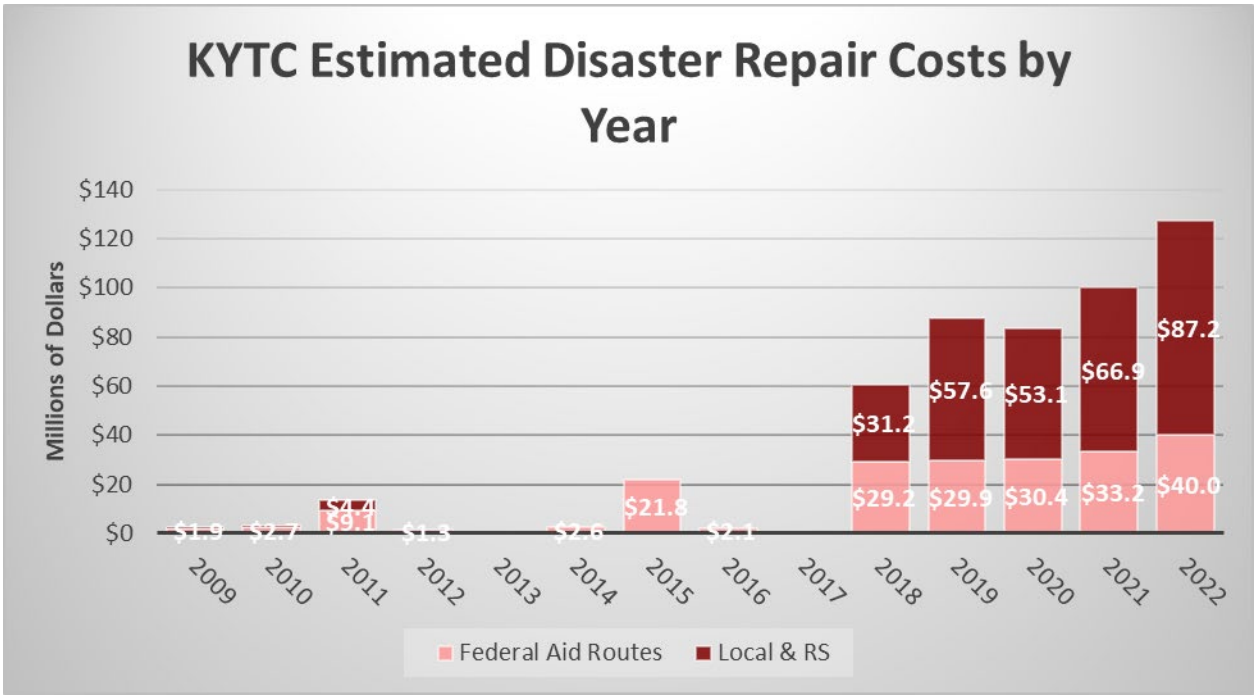


Simulated percentage difference in the mean annual number of days with precipitation of greater than one inch for the Southeast region for the 2041-2070 period with reference period of 1980-2000. Source: NCA4.

3. HISTORIC DAMAGES

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

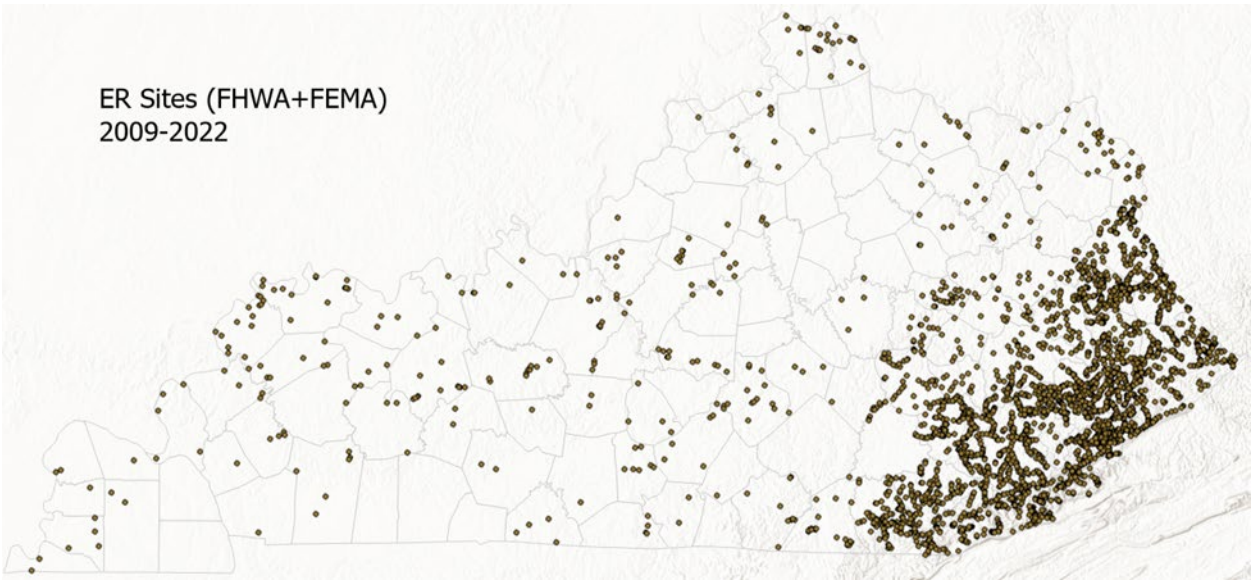
Where available, KYTC also includes in the database estimated costs for highway repairs. Estimated costs for repairs in the database total nearly $530 million. Of this total, $204 million was for damages to federal-aid routes and $301 million was for local and rural secondary routes. The database also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



KYTC estimated repair costs by year for declared disasters, 2009 through 2022.

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

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



4. RISK-BASED VULNERABILITY ASSESSMENT

In 2016, KYTC completed a risk-based vulnerability assessment of the state's transportation system to extreme weather and natural hazards. To conduct the vulnerability assessment, a hybrid approach consisting of three components was used: 1) gathering and analysis of available data on assets and hazards, 2) development and implementation of district-level workshops to elicit local expert knowledge on asset vulnerabilities, and 3) incorporating all data gathered into a single and ultimate assessment. Assessment results were compiled into a GIS database to serve as a central repository, facilitate easy data analysis of hazards and transportation assets, and enable KYTC users to produce maps and geovisualizations of transportation system vulnerabilities.

To guide the assessment, a risk matrix was developed to consider the likelihood and severity of consequences for hazard types as they pertain to the twelve KYTC districts.

Likelihood was defined on a scale of 1 to 5, where

1. Very Likely. Occurs repeatedly to assets across a wide area.
2. Likely. Occurs more than once to multiple assets.
3. May occur once to some assets.
4. May occur once to a few assets in a limited area.
5. Unlikely to occur.

Severity was defined on a scale of A to E, where

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

Likelihood and severity were then combined and assigned an overall risk score. High severity and likelihood result in higher risk (darker shades of red), while low severity and low likelihood result in lower risk (lighter shades of red).

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

The following figure shows the results of this assessment for each of KYTC's 12 districts:

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

The district-level assessment captures both the probability of assets being affected by future weather and disasters as well as the potential consequences of those events. Flood is demonstrated to be of high risk for all 12 KYTC districts, with the mountainous districts of 10, 11, and 12 having the highest risk. Landslide is high risk in the mountainous districts as well as district 6. Sinkholes are of highest risk in districts 3 and 4, where karst landscapes are common.

Qualitative data for the assessment was gathered at a series of workshops held with KYTC personnel at each of the twelve districts. Workshop participants engaged in discussion centered on flood, landslide, and sinkhole hazard mapping for roadway segments throughout their respective districts. This was followed by a series of keypad exercises whereby participants rated highway segments according to two criteria: each segment's vulnerability to natural hazards and each segment's criticality to the overall highway system.

In addition to this district-level assessment, an asset-level vulnerability assessment of KYTC's National Highway System (NHS), including highway segments, bridges, culverts, and other structures, was conducted for risk against the four major hazards of earthquakes, flooding, sinkholes, and landslides. This analysis compiled roadway and hazard data into a Geographic Information System (GIS) to identify segments vulnerable to each of the respective hazards according to the indicator data. The table below summarizes the relationship between these NHS assets statewide and selected hazard indicators.

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

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

Seismic vulnerability is identified according to the U.S. Geological Survey's National Seismic Hazard Model, which accounts for both the frequency and magnitude of seismic activity. Seismic hazard is

defined according to maximum Peak Ground Acceleration (PGA) with a 2% likelihood of exceedance in 50 years.

Flood vulnerability is identified according to Federal Emergency Management Agency's (FEMA) flood hazard mapping dataset. This 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. A flood with a 100-year recurrence interval has an approximately 1 percent chance of occurring in any given year. The 100-year floodplain encompasses areas that would be inundated if such a flood were to occur.

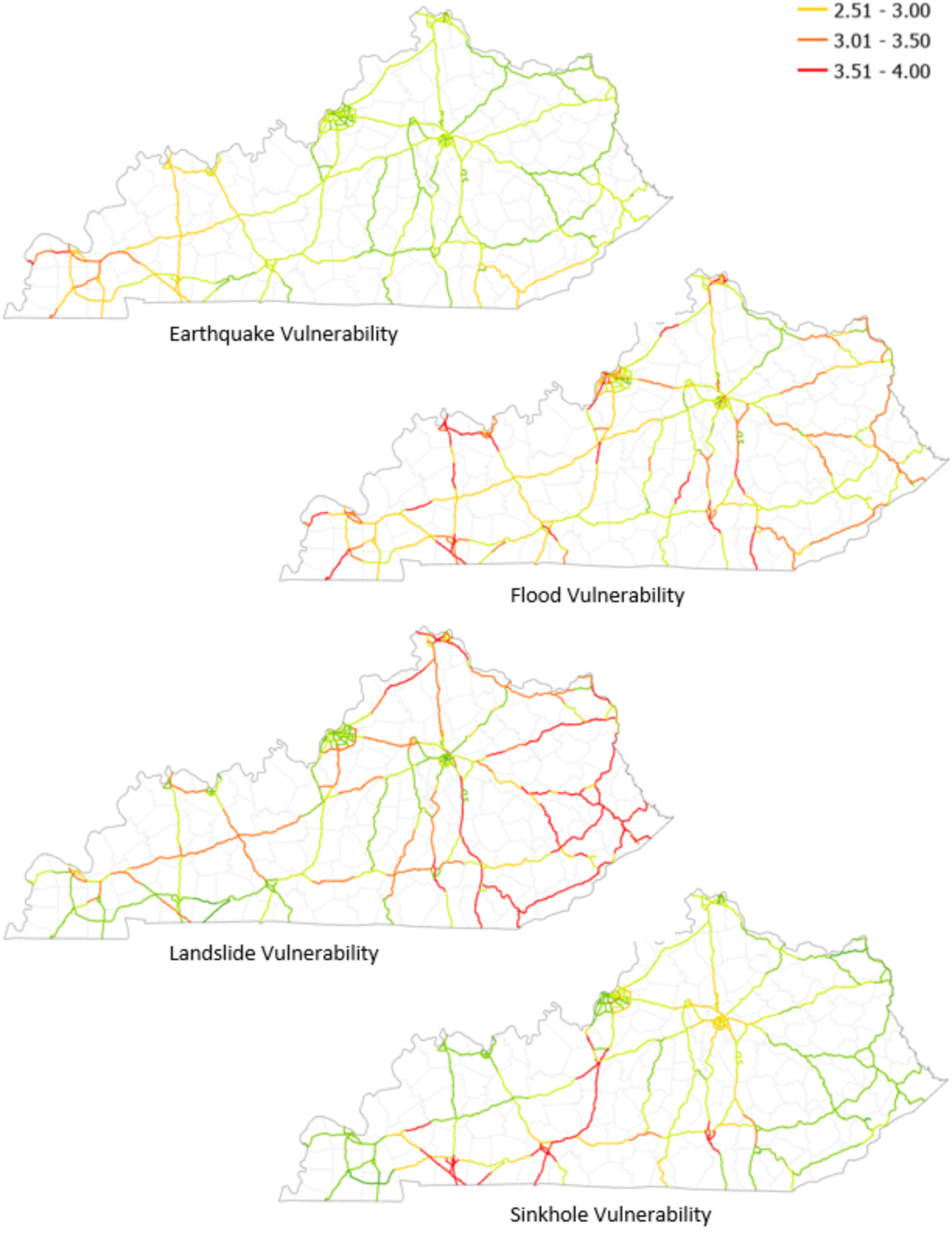
Sinkhole vulnerability is identified according to the Kentucky Geological Survey's (KGS) mapping of karst potential in the Commonwealth. Areas of high karst potential are vulnerable to sinkhole formation. Similarly, landslide vulnerability is identified according to KGS' mapping of statewide landslide potential.

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

Of the 287 NHS segments in this assessment, eighty-three were found to have high vulnerability to either earthquake, flood, landslide, or sinkhole. Of these eighty-three segments, thirteen had high vulnerability to two hazard types, and one other segment had high vulnerability to three hazard types. In terms of hazard types, four were vulnerable to earthquake, twenty-seven were vulnerable to flood, forty-five were vulnerable to landslide, and twenty-two were vulnerable to sinkhole. The figure below maps the VAST results of NHS vulnerability to each of these four hazards.

The VAST results 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 resilience 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 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.

Vulnerability assessment scoring tool (VAST) results for Kentucky's National Highway System (NHS). Higher numbers indicate higher vulnerability.



5. RESILIENCE IMPROVEMENT STRATEGIES

Climate and extreme weather events pose recognized risks to KYTC's transportation infrastructure. Unexpected events and long-term changes caused by these risks can have broad social, economic, and environmental consequences. While it is not realistic to be able to completely prevent the impacts related to climate risks, KYTC is implementing adaptation strategies that will help its infrastructure become more resilient to such events. Initial resiliency strategies are considered within a ten-year planning horizon to align with the Transportation Asset Management Plan.

KYTC understands the importance of incorporating natural based solutions that promote ecological processes into mitigation but did not immediately identify natural infrastructure strategies alongside hard surface transportation assets. Strategies such as permeable pavement consideration, green erosion plantings, etc will be incorporated in future iterations of the RIP when emerging information is better understood.

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

5.1. TEMPERATURE

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

Some of the main pavement vulnerabilities to extreme temperature include:

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

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

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

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

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

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

5.2. PRECIPITATION

Pavements

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

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

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

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

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

- Construction procedures. KYTC is improving the quality of pavement construction by placing increased emphasis on construction inspection, acceptance, and project delivery.

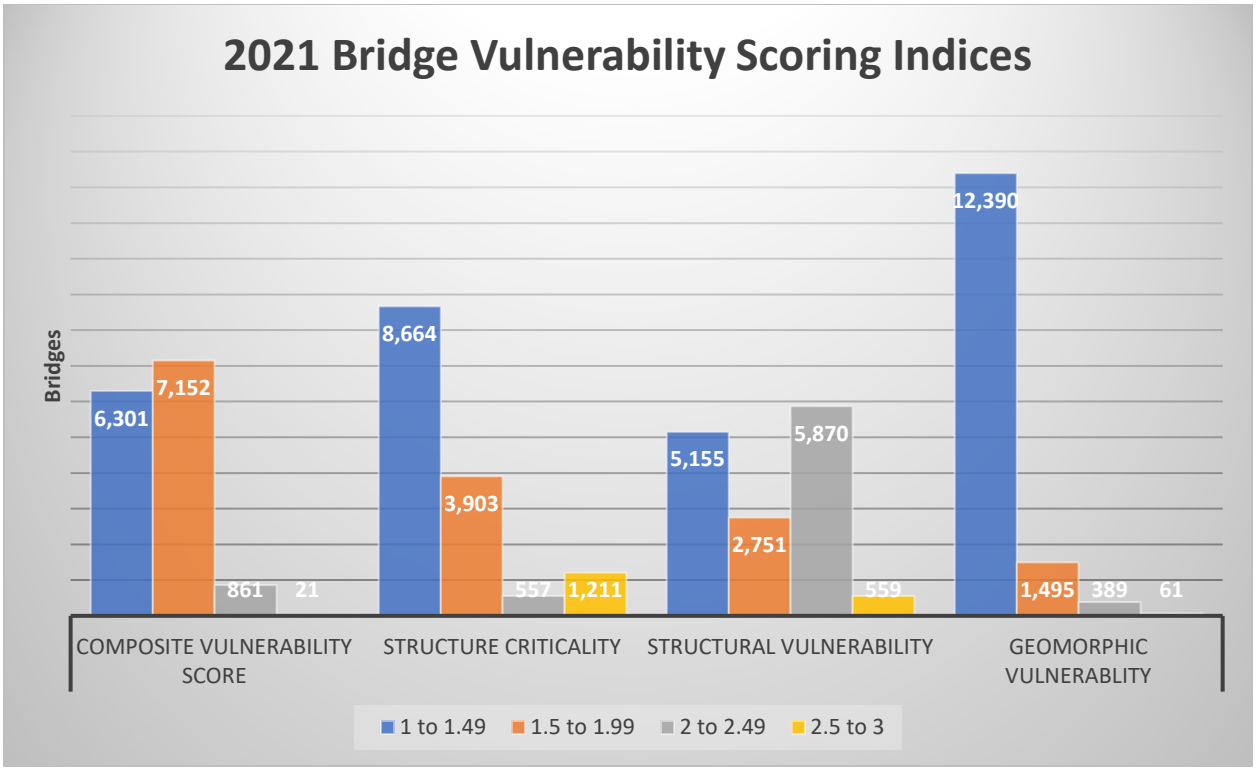
- Maintenance and operation activities. KYTC has increased efforts to seal cracks and joints in existing pavements and is currently investigating the use of asphalt pavement preservation techniques (e.g., chip seals, fog seals, microsurfacing) that are more effective in reducing permeability.
- Design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

Extreme weather events can potentially influence pavement treatment strategies over the long-term and KYTC considers these risks and adaption approaches while developing its LCP strategies. KYTC considers a balanced priority between preservation and major rehabilitation/reconstruction actions that not only ensures that good pavements continue to provide a good level-of-service for the road users, but pavement sections that are more vulnerable to extreme weather events receive a fair allocation of funding to address imminent risks. Based on routine vulnerability assessments, if a certain portion of the KYTC pavement network is found to be more vulnerable to extreme weather events, the pavement deterioration models, and treatment strategies will be recalibrated to help improve the network's overall resilience.

Bridges

As part of the 2018 FHWA pilot project on Extreme Weather, Proxy Indicators, and Asset Management, a bridge vulnerability rating methodology was developed that incorporated KYTC bridge evaluation data. The methodology produced bridge ratings for Geomorphic Vulnerability, Structural Vulnerability, and Structure Criticality. These scores were then combined to produce a Bridge Composite Vulnerability score.

The index is used as a supplement to the Bridge Management System and the asset management bridge project selection to ensure that all relevant goals and objectives, particularly safety and mobility, are appropriately considered in programming decisions.



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

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

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

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

Based on the results from the LCP analysis, the KYTC strategy creates a balanced approach to Asset Management and bridge replacement projects. The analysis recognizes that the worst-first approach, which focuses on replacement of bridges when they deteriorate into Poor condition, will leave less money for preservation of bridges in Good and Fair conditions. This, in turn, will yield ineffective results

leading to more costly repairs or replacements in the future. KYTC avoids this by using its asset management program to target Fair-condition bridges where strategic preservation and rehabilitation can restore good condition or keep them well away from the Poor category.

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

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

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

5.3. NEXT STEPS

KYTC has an ongoing project with the Kentucky Transportation Center to evaluate transportation resiliency and translate the efforts into practice and policy. The research addresses critical assets across all transportation modes to determine climate and natural hazard vulnerabilities and identify resiliency improvement needs. An inventory of critical transportation assets has been developed as a first step for analysis. Using the results below will assist KYTC with prioritization of strategies.

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

Transportation Asset	Summary	GIS?
All Roads Measured	89134.2 miles	Y
Hospitals	69 acute license, 28 critical access, 12 psychiatric, 6 rehab (115 total)	Y
City Points	420 city points	Y
Dams	1084 dams	Y
Bridge Locations	18801 bridges, 2853604.5 miles	Y
Airports	111 heliports, 148 airports, 3 ultralights	Y
FAA Airport Runways	59 runways, 162125009.9 sq. feet	Y
Truck Stop Parking	36 stops, 1189 parking spots	Y
North American Rail Network	3583.3 miles	Y
Rail Switchyards	80 switchyards, 153838148.7 sq. feet	Y
Amtrak Routes	198.1 miles	Y
Amtrak Stations	7 stations	Y
Commercially Navigable Rivers	1160.1 miles	Y
All Navigable Waterways	2085.5 miles	Y
Major Ports	7 ports	Y
All Ports	656 ports	Y
Ferry Routes	22055.9 miles	Y
Ferry Terminals	16 terminals	Y
Waterway Locks	23 locks	Y
Oil and Gas Wells	158282 wells	Y
Intermodal Freight Air to Truck	12 intermodal connections	Y
Intermodal Freight Rail	4 intermodal connections	Y
Transit Agencies	4 agencies	Y
Transit Agencies Routes	3804.3 miles	Y
Transit Agencies Stops	1675 stops	Y
Bicycle and Pedestian Facilities	4785.7 miles	Y

In addition, research is utilizing data on where transportation system damages have occurred historically to better understand future likelihoods of damages. KYTC's emergency repair database contains records back to 2009 on when and where transportation system damage has resulted from extreme weather events. The database shows that most damages result from high precipitation events that trigger such

hazards as flash flooding, rockfalls, erosion, embankment failures, and debris flows. These high precipitation events are particularly problematic in mountainous areas of eastern Kentucky, where fast rising water and swiftly moving currents can wreak havoc to communities and transportation assets located in valleys below the rugged terrain.

Data from the emergency repair database is being linked with historical weather in the form of daily precipitation and temperature records to develop a probabilistic model of extreme weather and roadway damages. This research effort is still ongoing, but early results indicate that this model can be applied with future climate projection data to aid in long-range planning for transportation system damages associated with climate change.

These ongoing research efforts intend to produce results that can feed directly into this current and future iterations of Kentucky's Resilience Improvement Plan. This model will assist KYTC in identifying where and to what extent damages are likely to occur and where resiliency improvement measures would be most beneficial. The results will be used to calculate the costs of action versus inaction and will be translated into policies, design practices, and guidance to direct KYTC project and operations investments and feed directly into future updates of this Transportation Resilience Improvement Plan.

Other resiliency related efforts include:

- Increased inventories. KYTC is in the process of inventorying small drainage assets using a mobile app system to assess condition, needs, and help identify areas of concern and prioritize project selection. The initial pilot will focus on eastern Kentucky where there is a high probability of impact to transportation assets due to a high precipitation event.
- Materials evaluations. KYTC recognizes that pavement is not the only material that is impacted by changing climate projections. Culvert and drainage pipe material selection policy will be revised with resiliency considerations.
- Policy development. KYTC is developing formal agency goals and response policies for resiliency. Design policies will also be added with respect to vulnerability consideration of bridges and material selection.
- Cost modeling. The climate projections paired with historic records of damage will yield probabilistic modeling that will help quantify the cost of natural hazards and the cost to improve infrastructure for anticipated events.

APPENDIX A: VULNERABILITY ASSESSMENT OF NHS FOR KYTC

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

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in cooperation with
Kentucky Transportation Cabinet
Commonwealth of Kentucky

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University of Kentucky

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

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

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

17. Key Words extreme weather, vulnerability assessment, natural hazard, resilience, flood, earthquake, landslide, sinkhole		18. Distribution Statement Unlimited with approval of the Kentucky Transportation Cabinet	
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Executive Summary

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

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

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

1. Introduction

1.1.Overview

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

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

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

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

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

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

1.2.Assessment Framework

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

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

1.3.Historical and Projected Climate in Kentucky

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

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

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

1.4.Hazards Considered

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

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

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

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

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

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

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

1.4.1. Seismic

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

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

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

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

[5] USGS, "Earthquake Glossary."

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

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

1.4.2. Flood

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

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

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

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

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

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

1.4.3. Landslide

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

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

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

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

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

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

1.4.4. Karst

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

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

1.4.5. Other Hazards

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

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

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

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

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

1.5. KYTC District Workshops

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

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

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

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

1.5.1. Mapping Exercises

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

1.5.2. Polling Results

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

Criticality scale

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

Impacts scale

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

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

1.5.3. Consensus Workshop

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

1.6.Results

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

1.6.1. VAST

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

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

Data inputs for VAST are organized into three types:

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

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

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

1.6.2. VAST Data Inputs

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

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

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

1.6.3. VAST Results

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

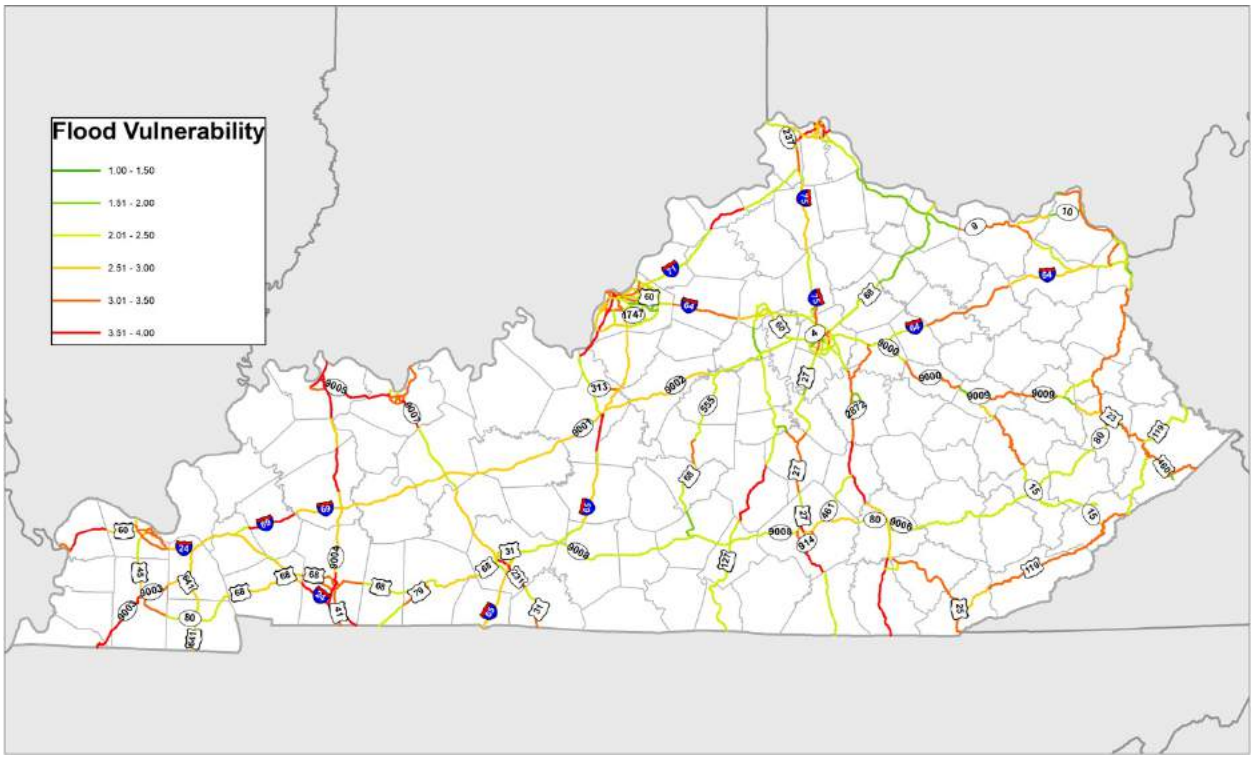

Figure 1-1. Mapped VAST results for flood vulnerability of Kentucky's NHS

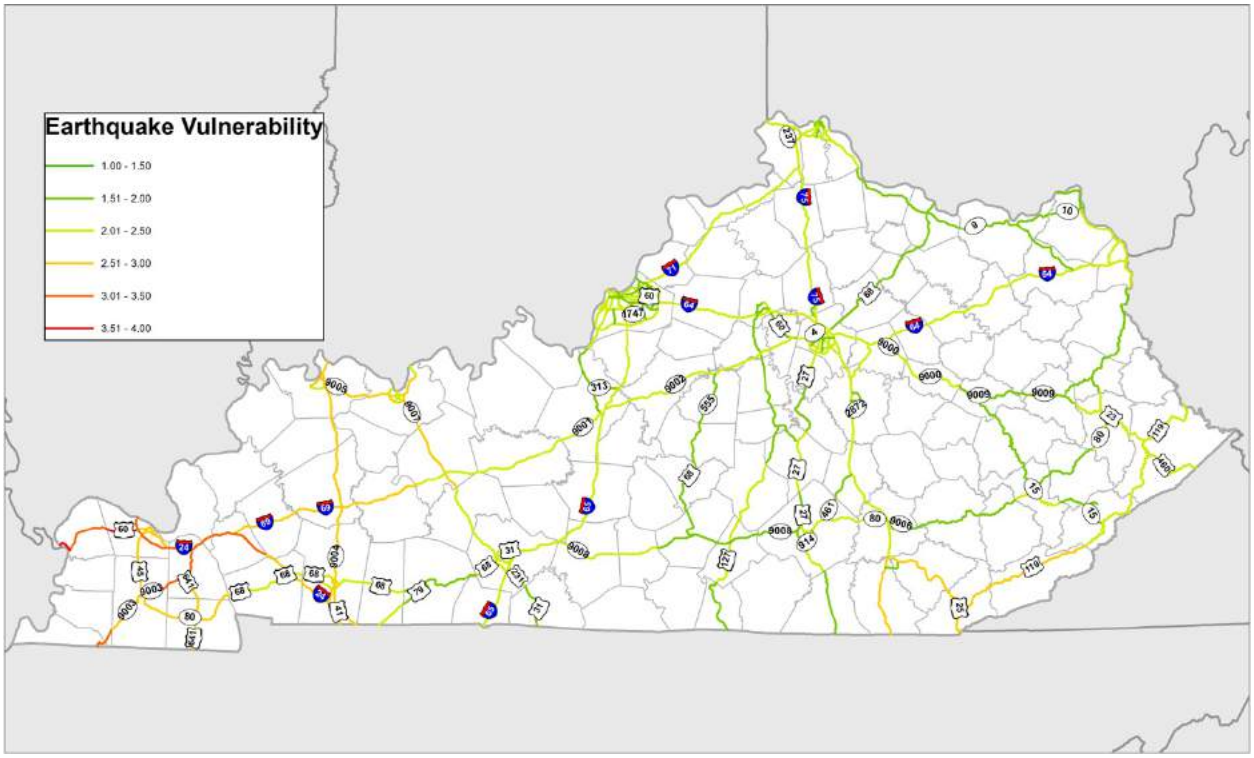

Figure 1-2. Mapped VAST results for earthquake vulnerability of Kentucky's NHS

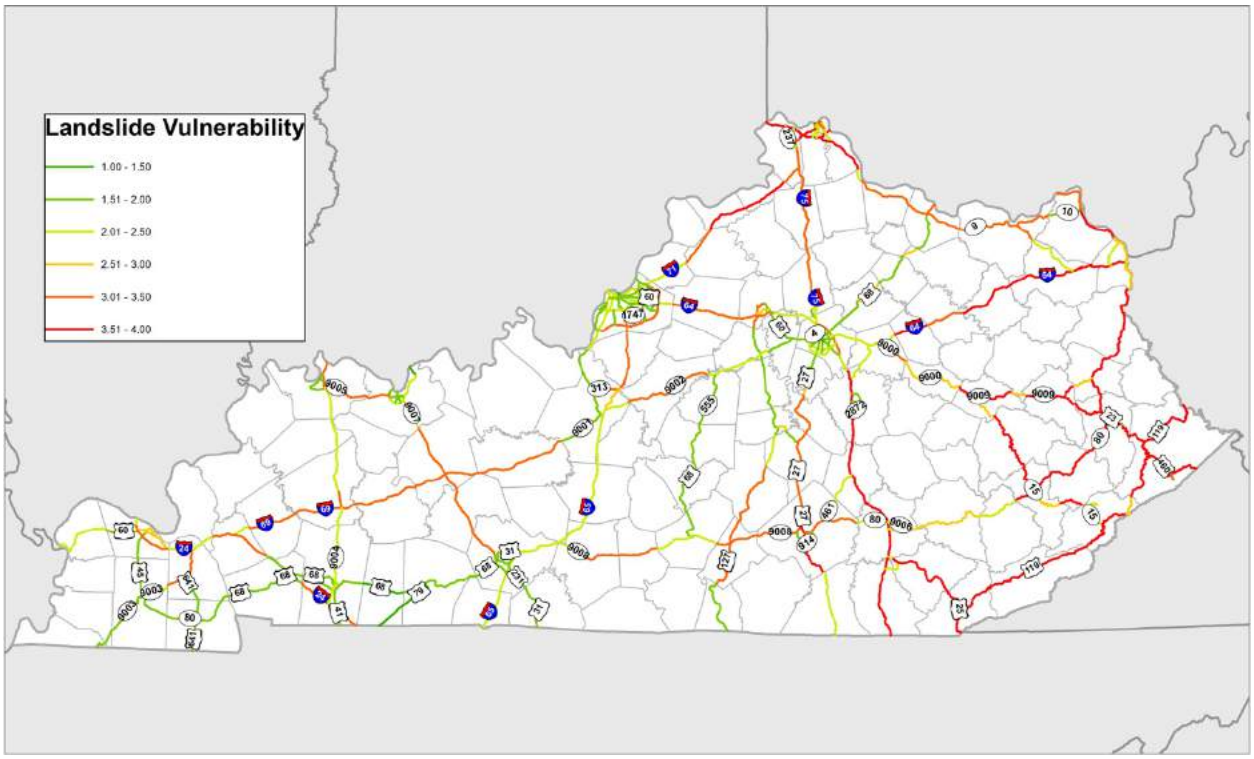

Figure 1-3. Mapped VAST results for landslide vulnerability of Kentucky's NHS

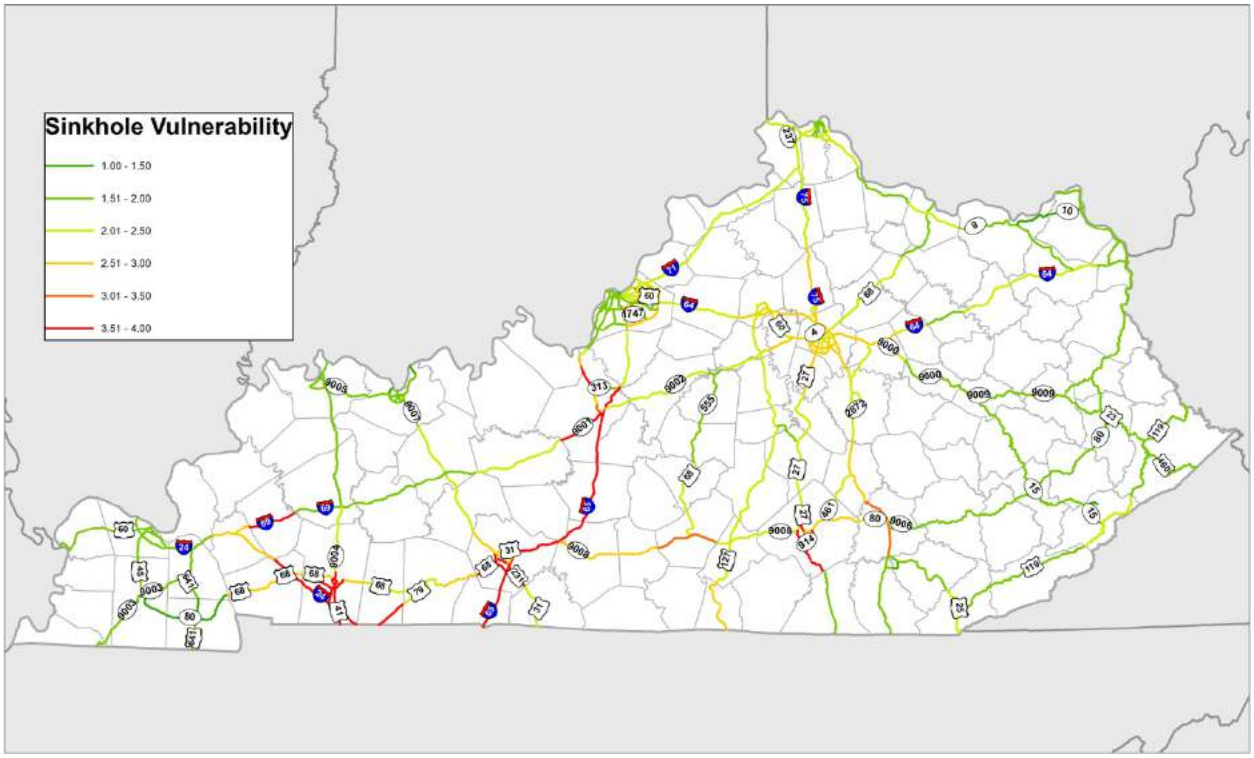

Figure 1-4. Mapped VAST results for sinkhole vulnerability of Kentucky's NHS

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

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

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

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

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

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

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

1.6.4. Secondary Results

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

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

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

1.7.Discussion

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

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

2. KYTC District 2

2.1.District Overview

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

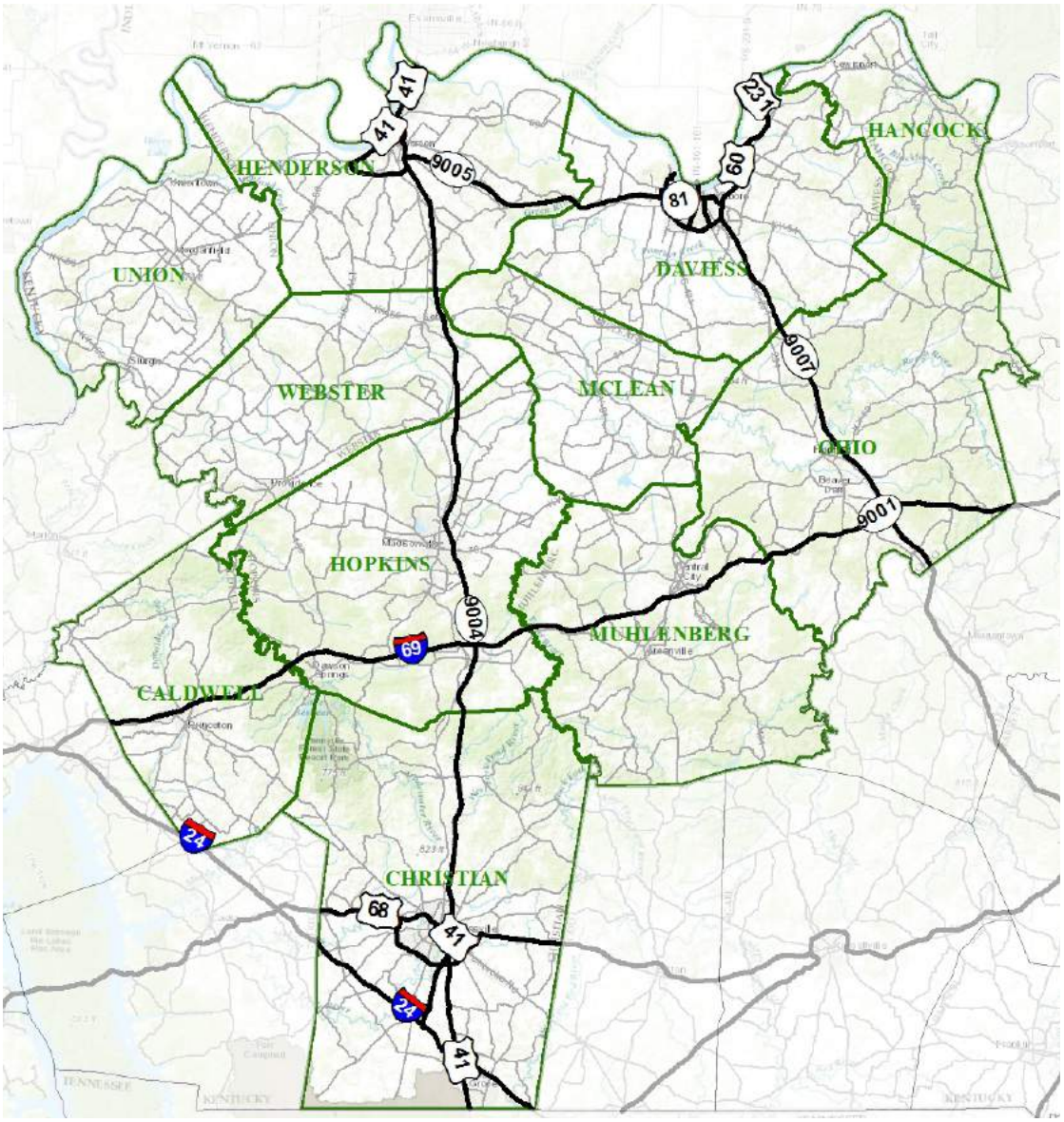

Figure 2-1. KYTC District 2 NHS

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

2.2.Hazards

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

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

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

2.2.1. Earthquake

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

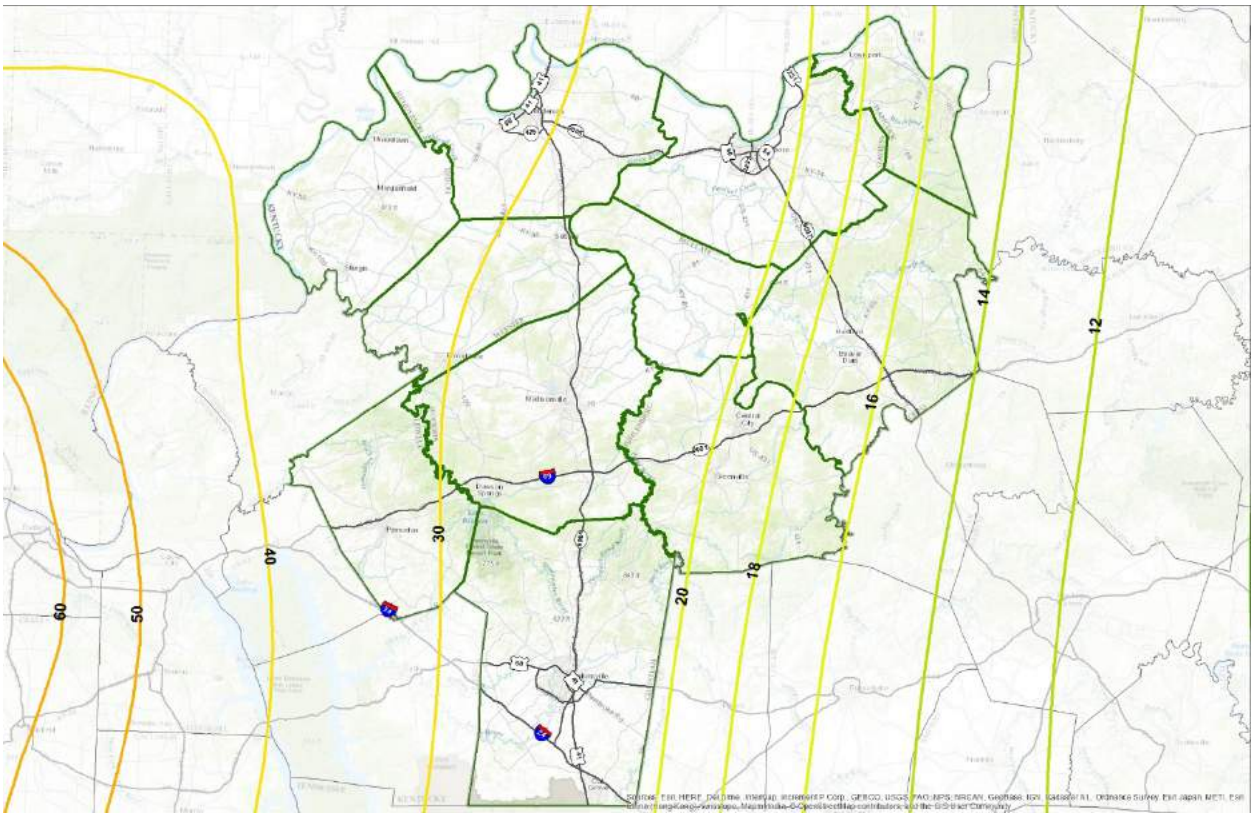

Figure 2-2.USGS PGA zones in KYTC District 2

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

2.2.2. Flood

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

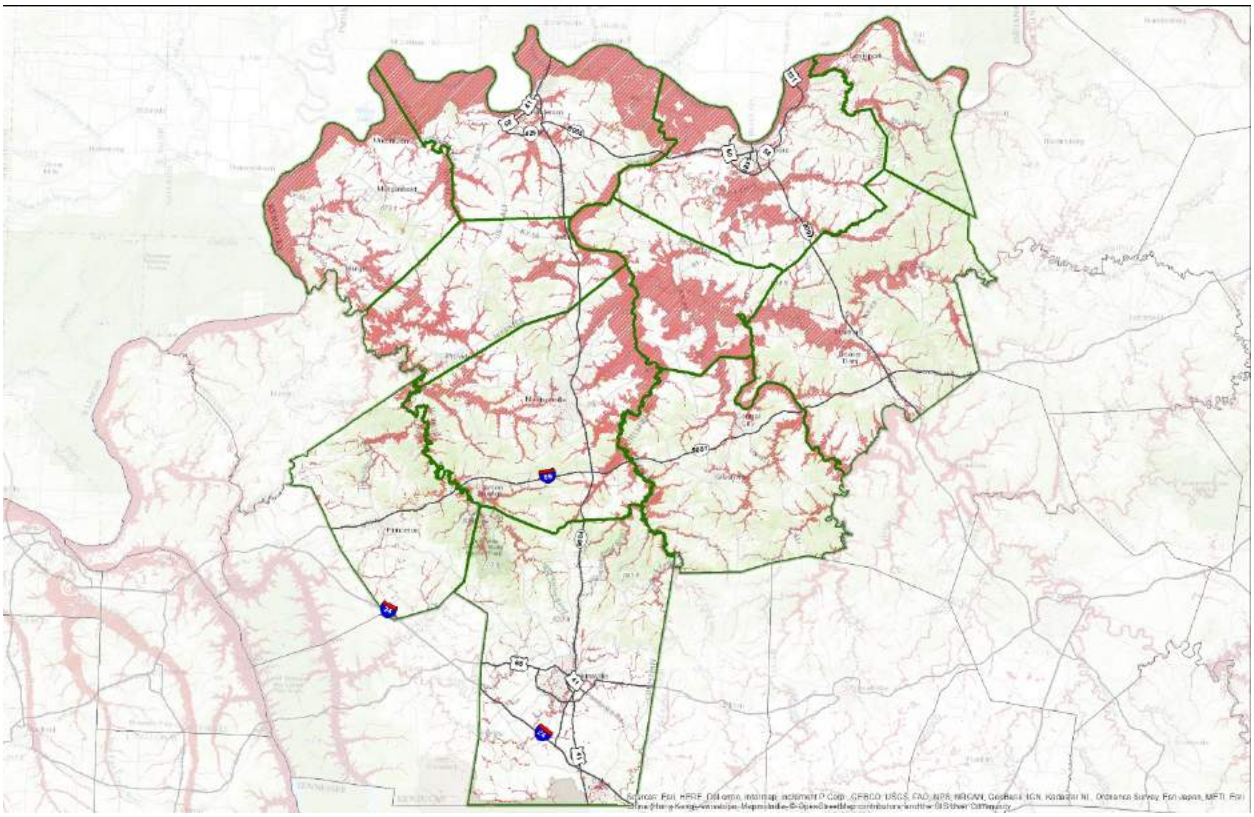

Figure 2-3. KYTC District 2; location of 100-year floodplain

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

2.2.3. Landslide

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

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

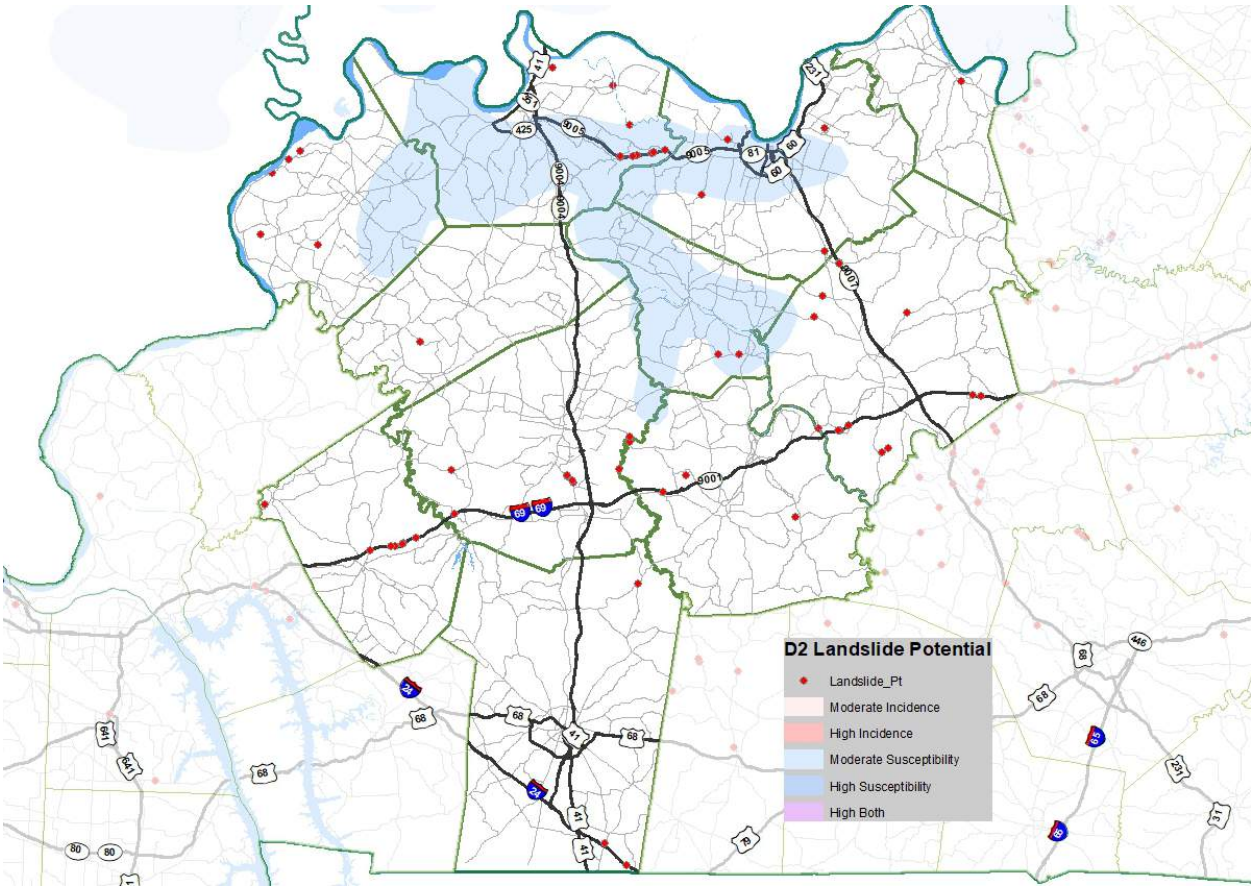

Figure 2-4. KYTC District 2 documented landslides and landslide susceptibility

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

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

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

2.2.4. Karst

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

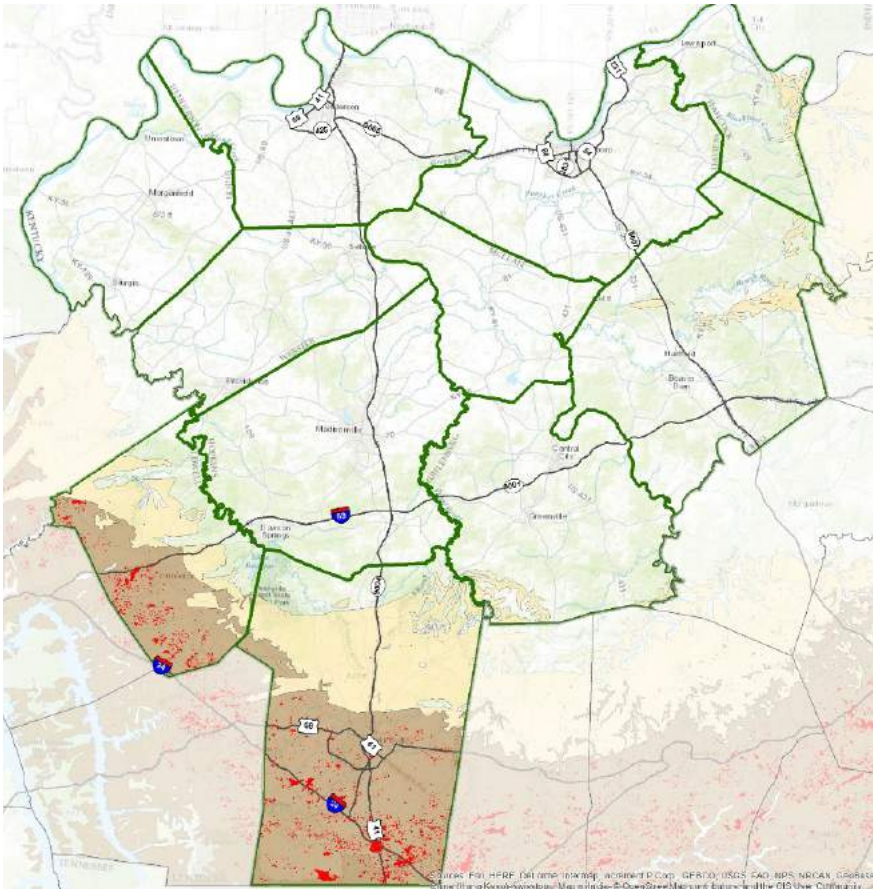

Figure 2-5. Karst potential and sinkholes in KYTC District 2

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

2.2.5. Other Meteorological Hazards

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

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

2.3.Workshop

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

2.3.1. Polling Results

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

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

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

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

2.3.2. Map Exercise

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

Table 2-3. District 2 NHS segments and flood

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

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

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

2.3.3. Workshop Discussion

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

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

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

2.3.4. Roadways outside of the NHS that flood

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

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

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

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

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

2.3.5. Maintenance facilities flooding

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

2.4.Results

2.4.1. Identification of most vulnerable assets

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

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

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

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

2.4.2. Worst Case Scenario

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

3. KYTC District 3

3.1.District Overview

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

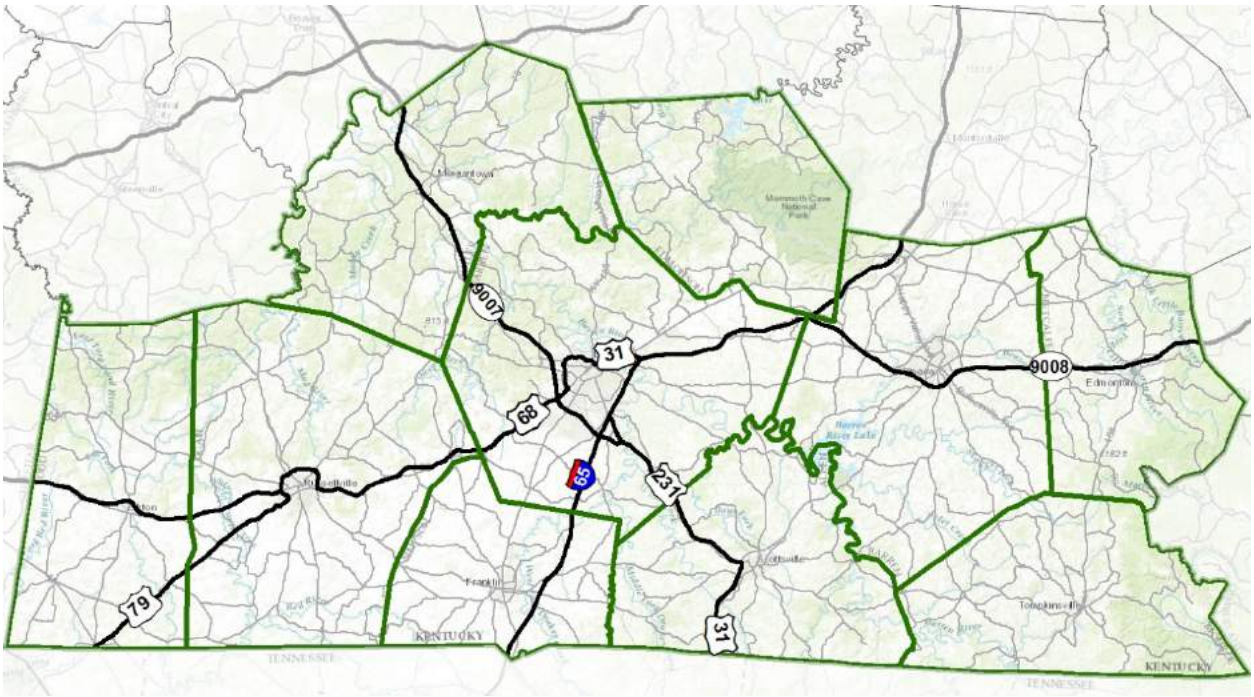

Figure 3-1. KYTC District 3 NHS

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

3.2.Hazards

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

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

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

3.2.1. Earthquake

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

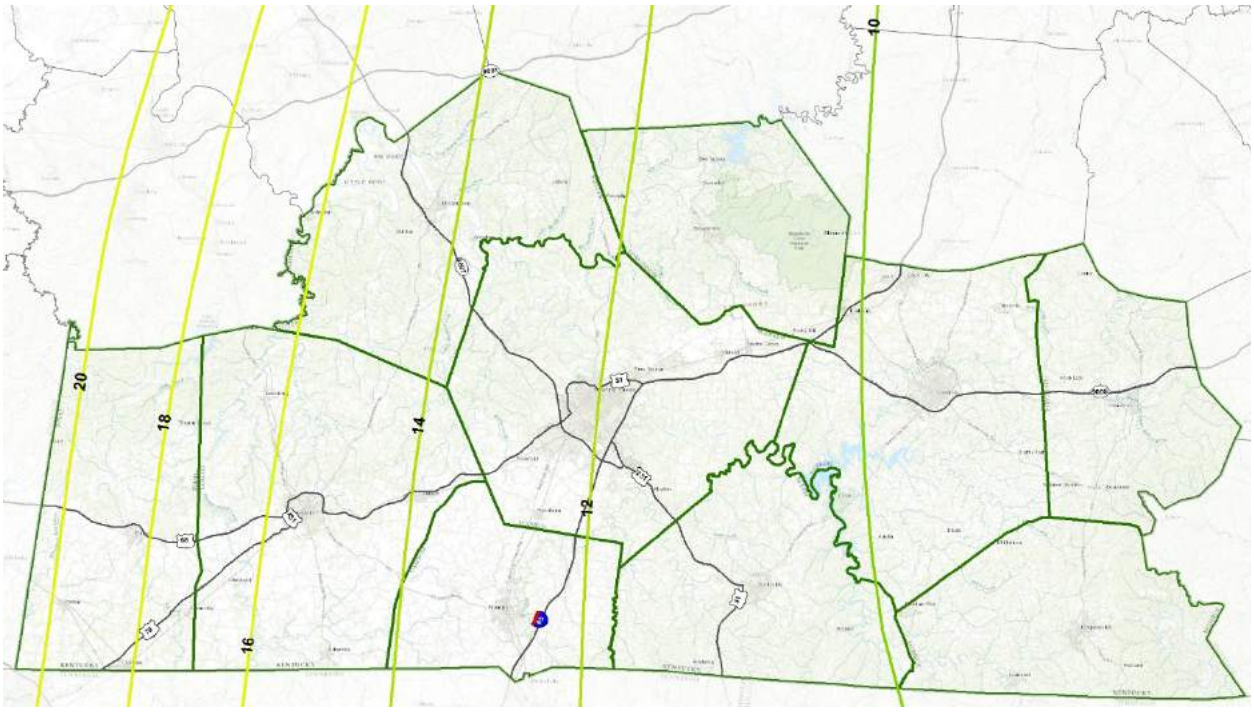

Figure 3-2. USGS PGA zones in KYTC District 3

3.2.2. Flood

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

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

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

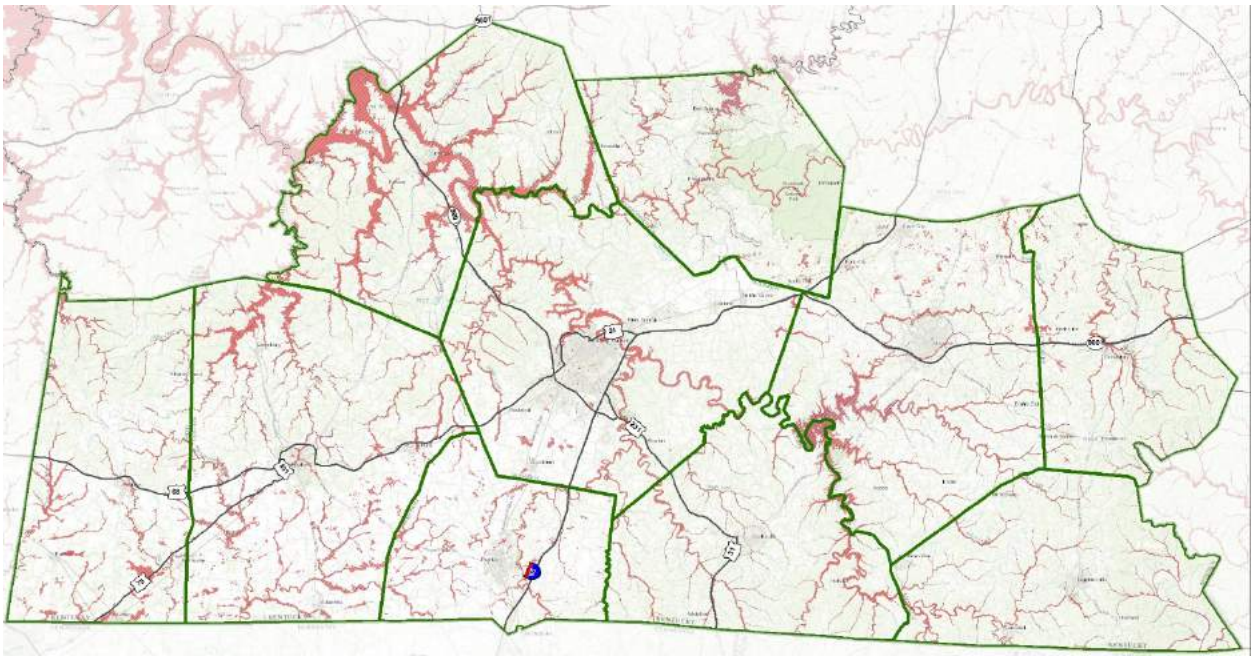

Figure 3-3. KYTC District 3; location of 100-year floodplain

3.2.3. Landslide

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

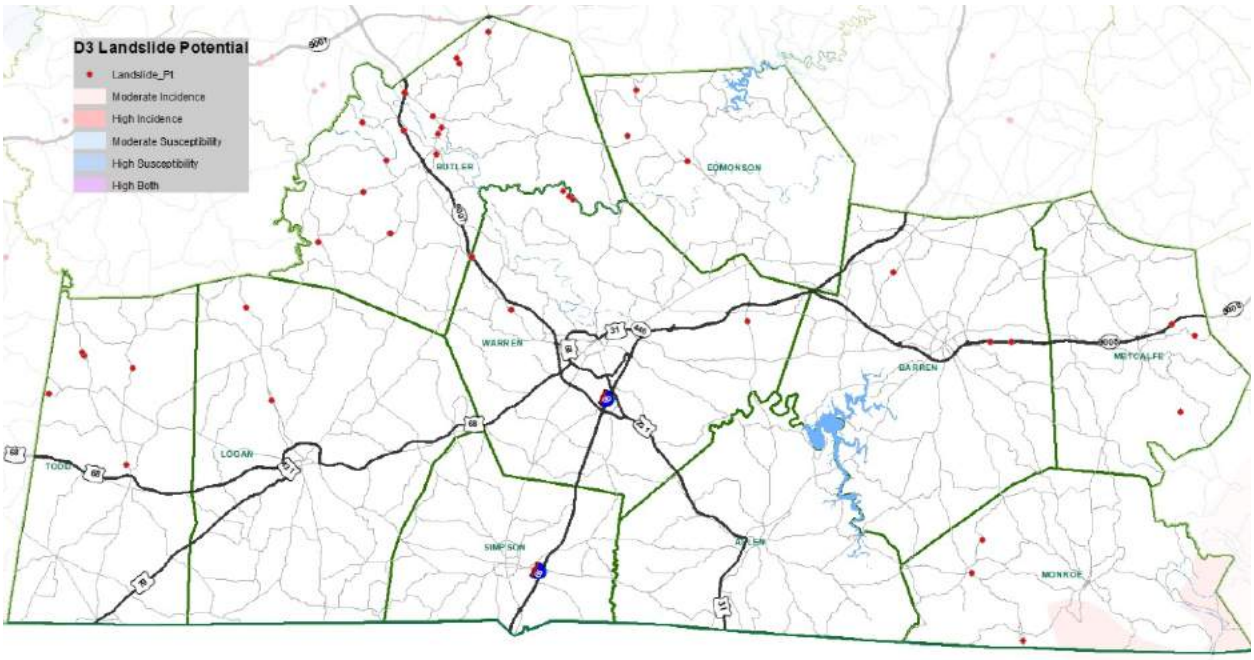

Figure 3-4. KYTC District 3 documented landslides and landslide susceptibility

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

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

3.2.4. Karst

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

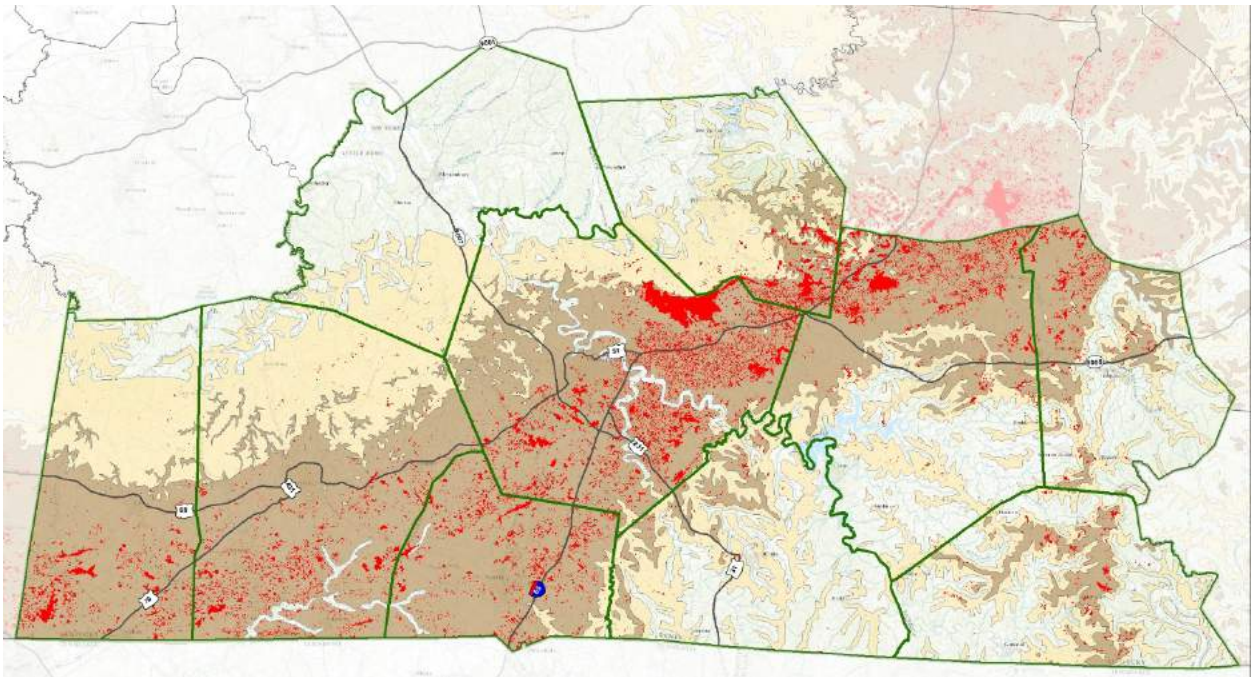

Figure 3-5. Karst potential and sinkholes in KYTC District 3

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

3.2.5. Other Meteorological Hazards

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

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

3.3.Workshop

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

3.3.1. Polling Results

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

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

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

3.3.2. Map Exercise

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

Table 3-3. District 3 NHS segments and flood

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

3.3.3. Workshop Discussion

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

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

3.3.4. Roadways outside of the NHS that flood

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

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

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

3.3.5. Maintenance facilities flooding

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

3.3.6. Consensus workshop

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

Table 3-4. Results of District 3 consensus workshop

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

			Need better pay to keep good workers			

3.4.Results

3.4.1. Identification of most vulnerable assets

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

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

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

3.4.2. Worst case scenario

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

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

4. KYTC District 4

4.1.District Overview

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

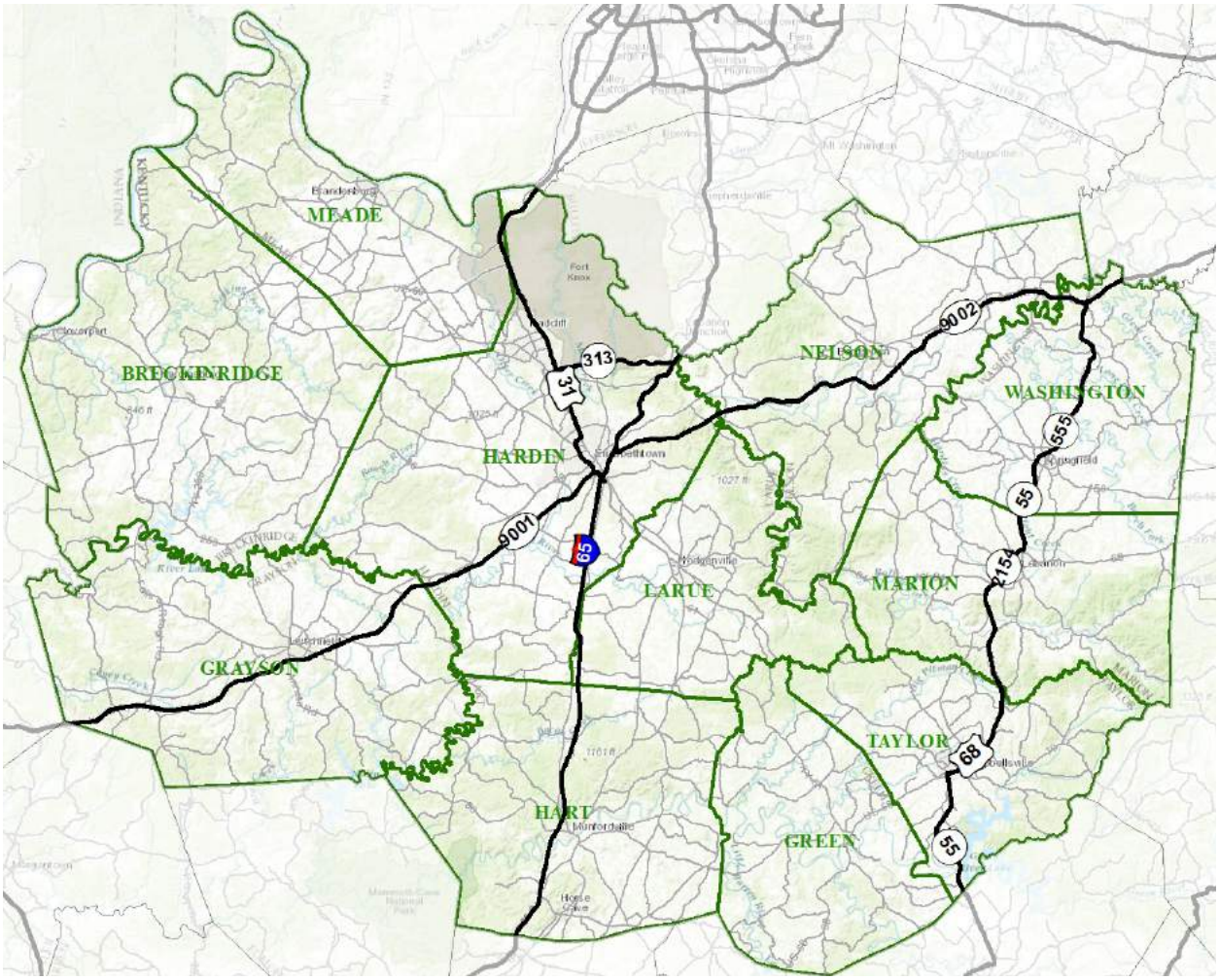

Figure 4-1. KYTC District 4 NHS

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

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

4.2.Hazards

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

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

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

4.2.1. Earthquake

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

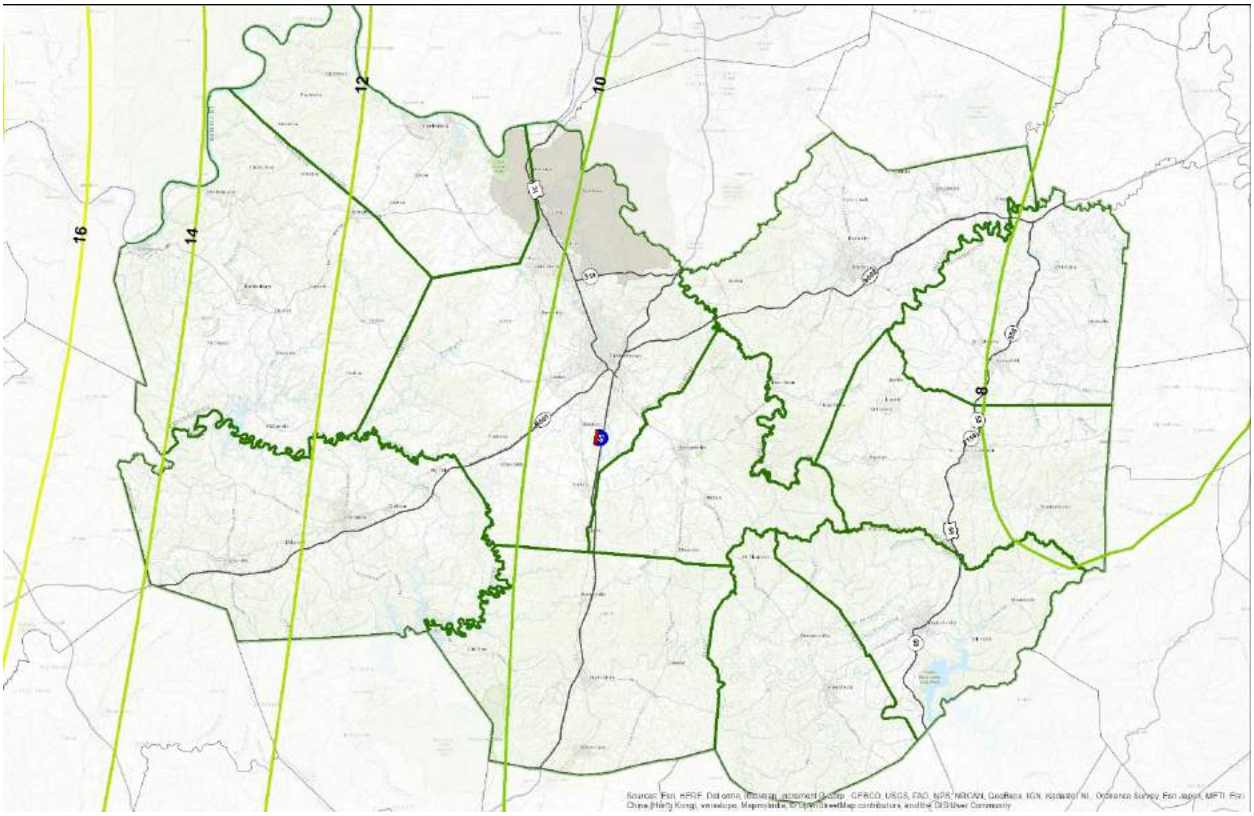

Figure 4-2. USGS PGA zones in KYTC District 4

4.2.2. Flood

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

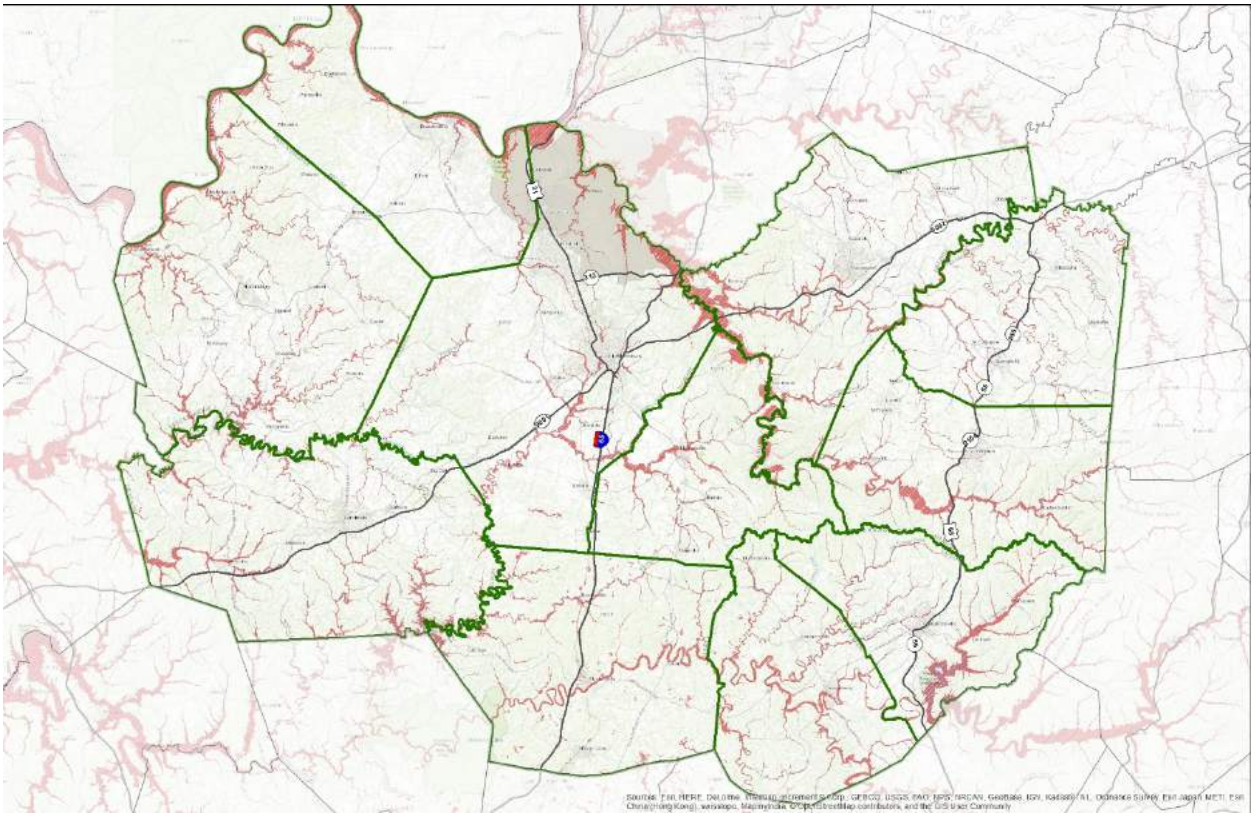

Figure 4-3. KYTC District 4; location of 100-year floodplain

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

4.2.3. Landslide

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

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

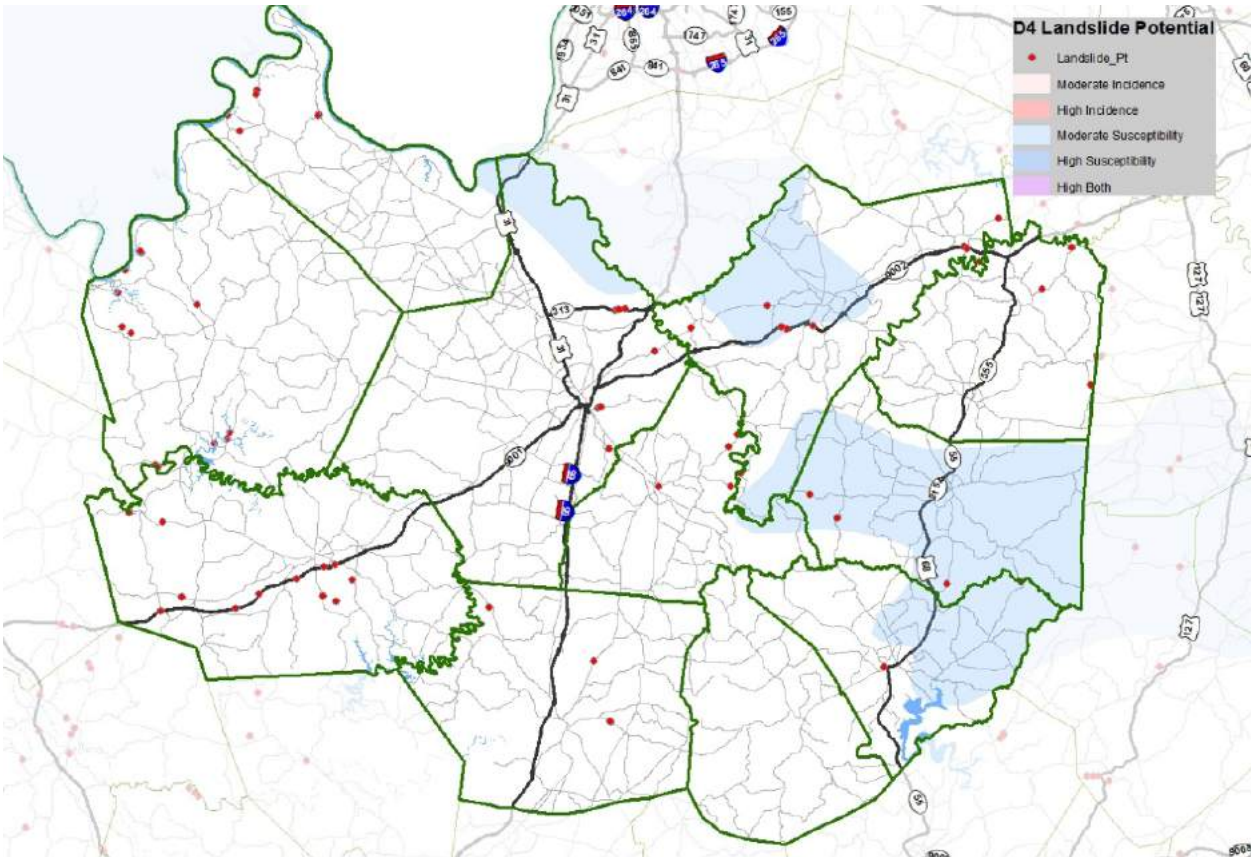

Figure 4-4. KYTC District 4 documented landslides and landslide susceptibility

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

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

4.2.4. Karst

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

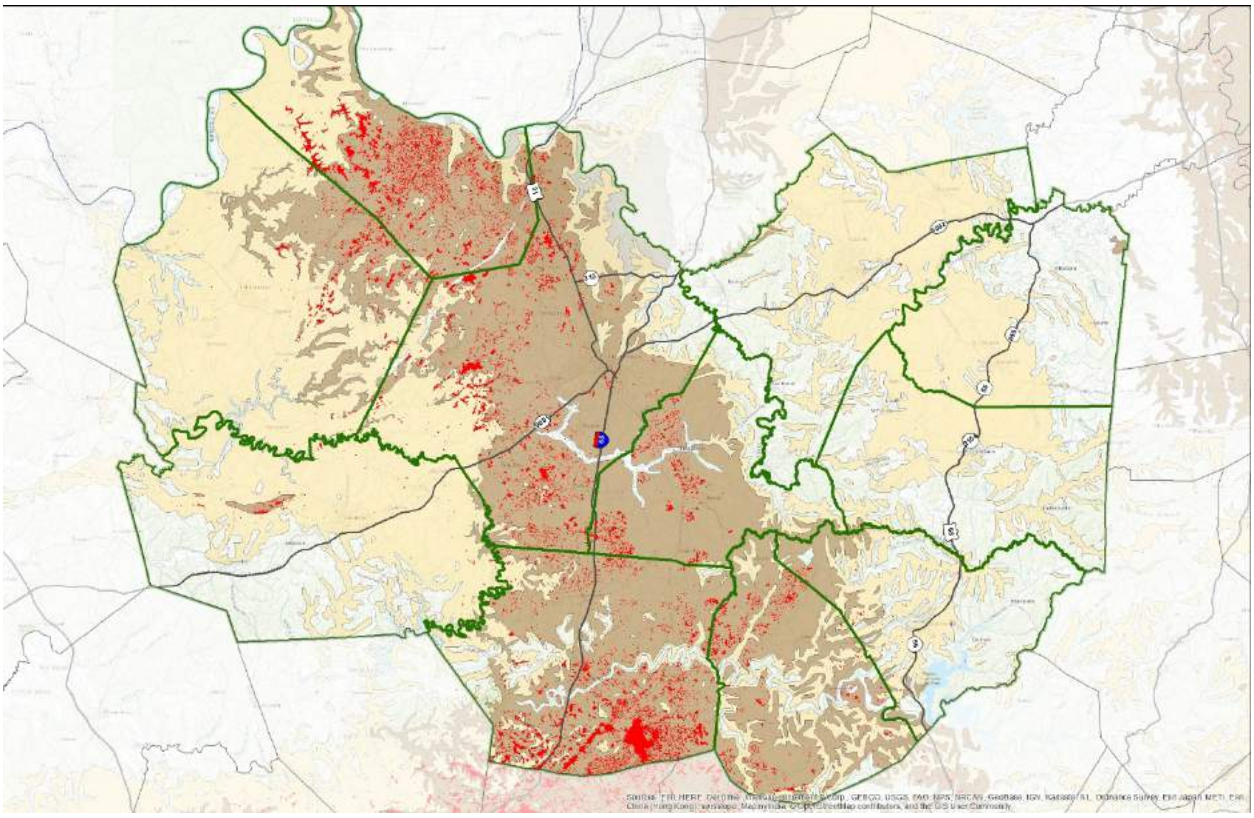

Figure 4-5. Karst potential and sinkholes in KYTC District 4

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

4.2.5. Other Meteorological Hazards

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

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

4.3.Workshop

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

4.3.1. Polling Results

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

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

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

4.3.2. Map Exercise

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

Table 4-3. District 4 NHS segments and flood

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

4.3.3. Workshop discussion

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

4.3.4. Maintenance facilities flooding

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

4.3.5. Roadways outside of the NHS that flood

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

4.3.6. Consensus workshop

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

Table 4-4. Results of District 4 consensus workshop

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

4.4.Results

4.4.1. Identification of most at vulnerable assets

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

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

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

4	Larue	I-65	**4.00**	Sinkhole

4.4.2. Worst case scenario

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

5. KYTC District 5

5.1.District Overview

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

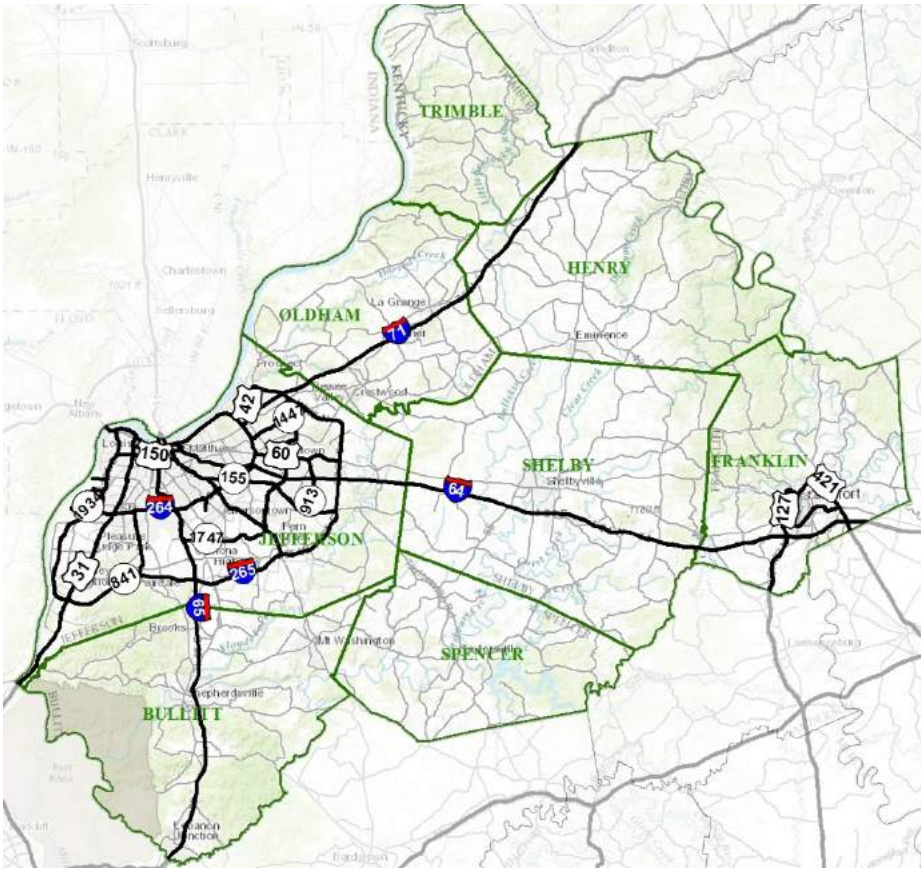

Figure 5-1. KYTC District 5 NHS

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

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

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

5.2.Hazards

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

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

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

5.2.1. Earthquake

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

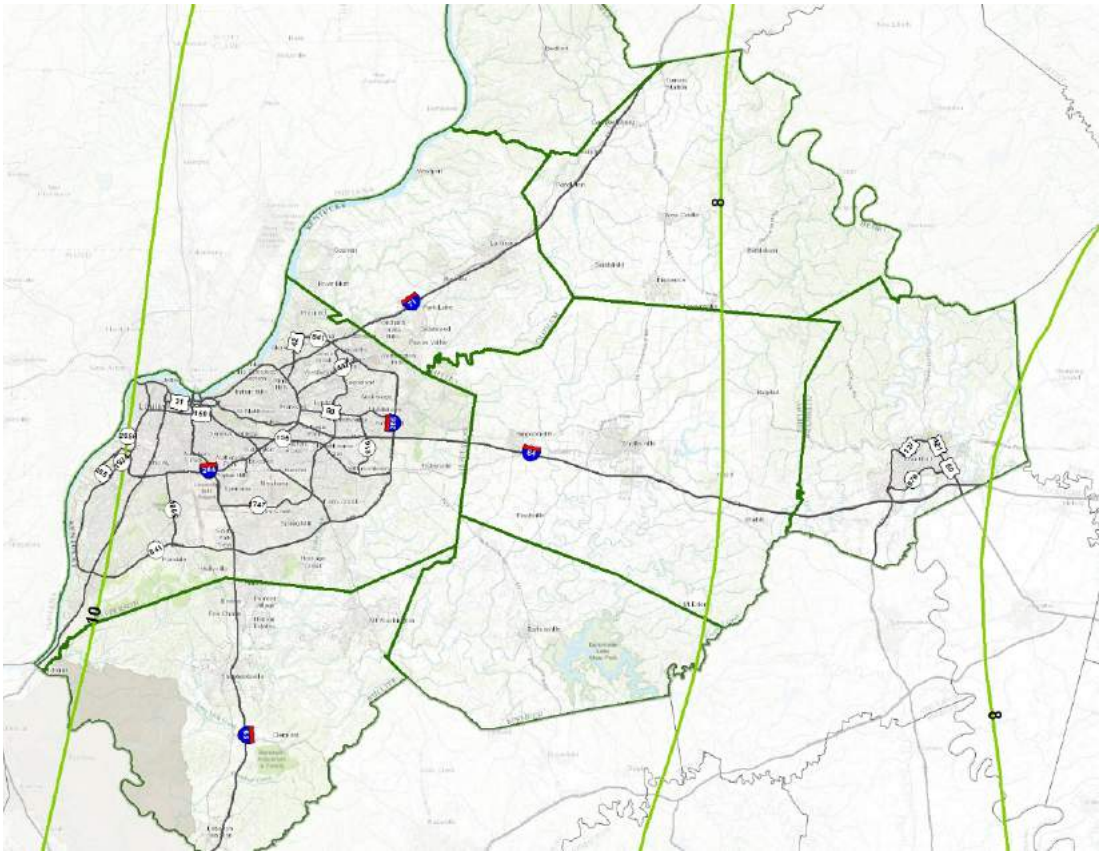

Figure 5-2. USGS PGA Zones in KYTC District 5

5.2.2. Flood

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

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

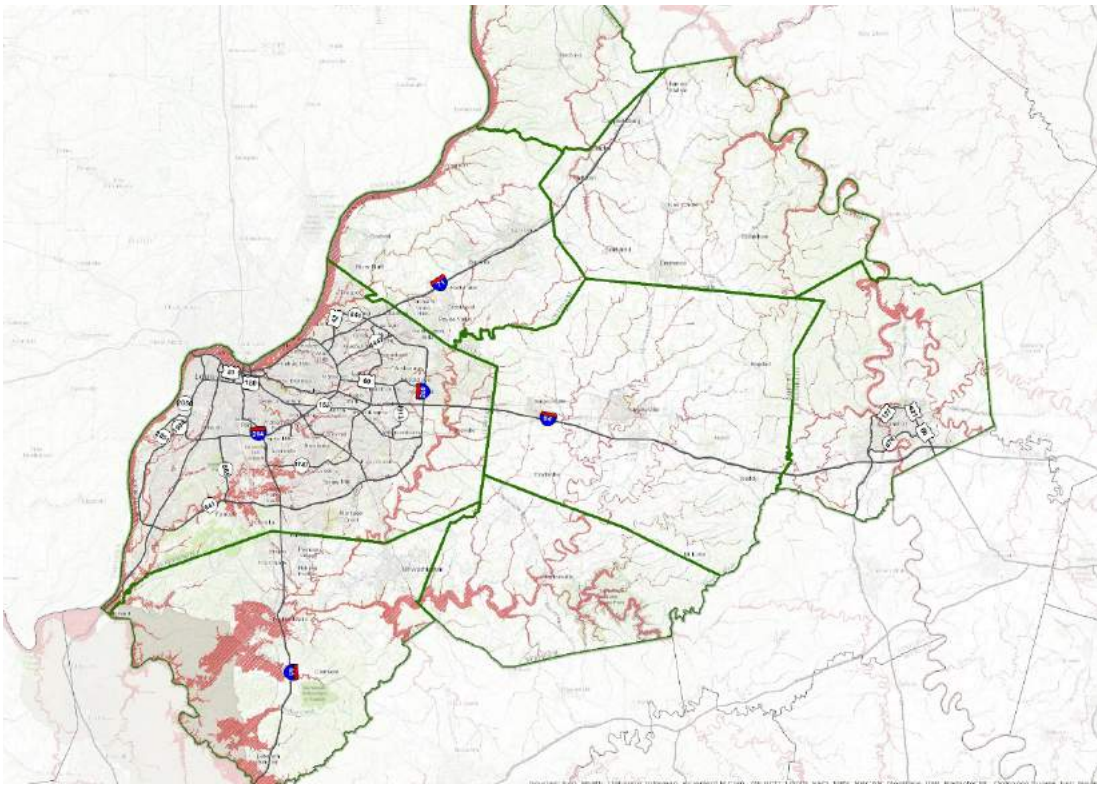

Figure 5-3. KYTC District 5; location of 100-year floodplain

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

5.2.3. Landslide

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

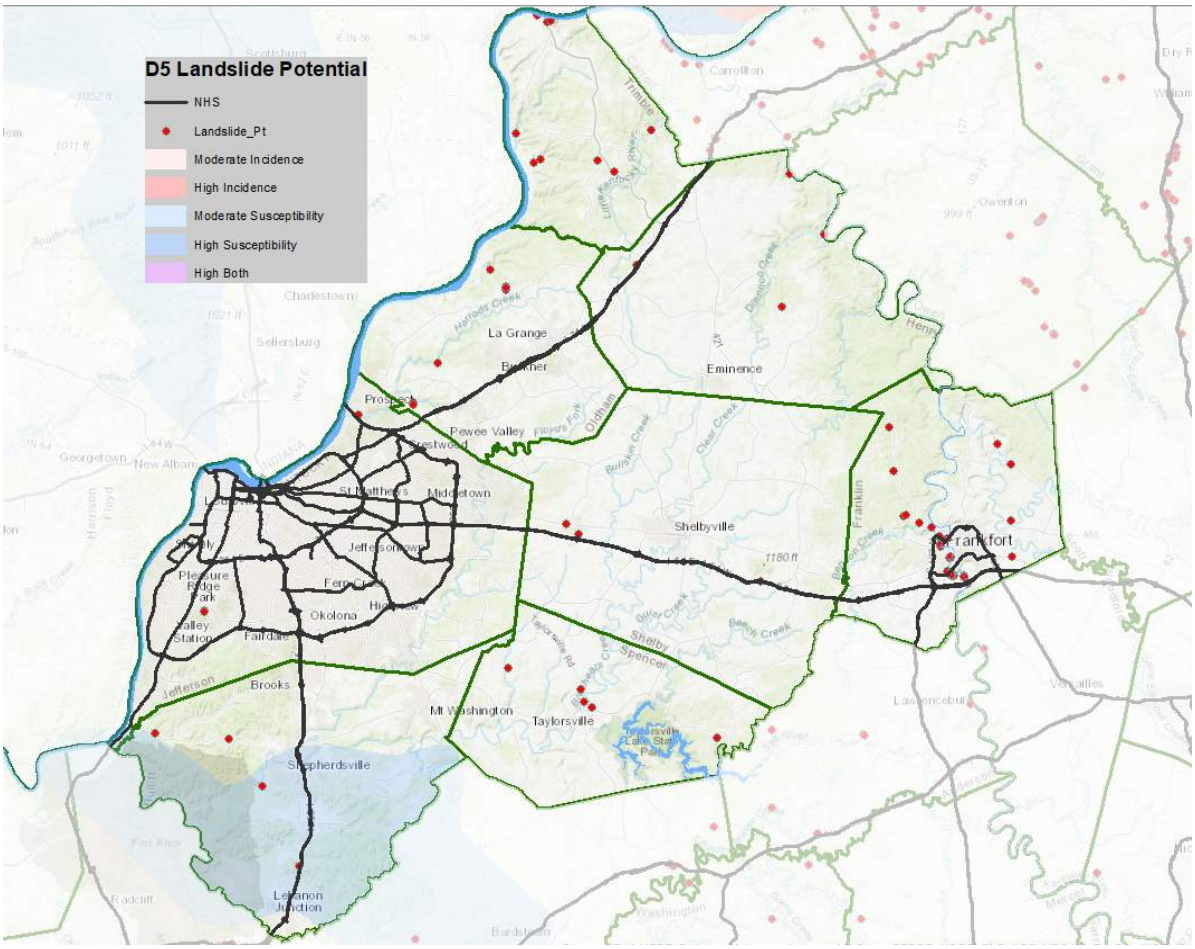

Figure 5-4. KYTC District 5 documented landslides and landslide susceptibility

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

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

5.2.4. Karst

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

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

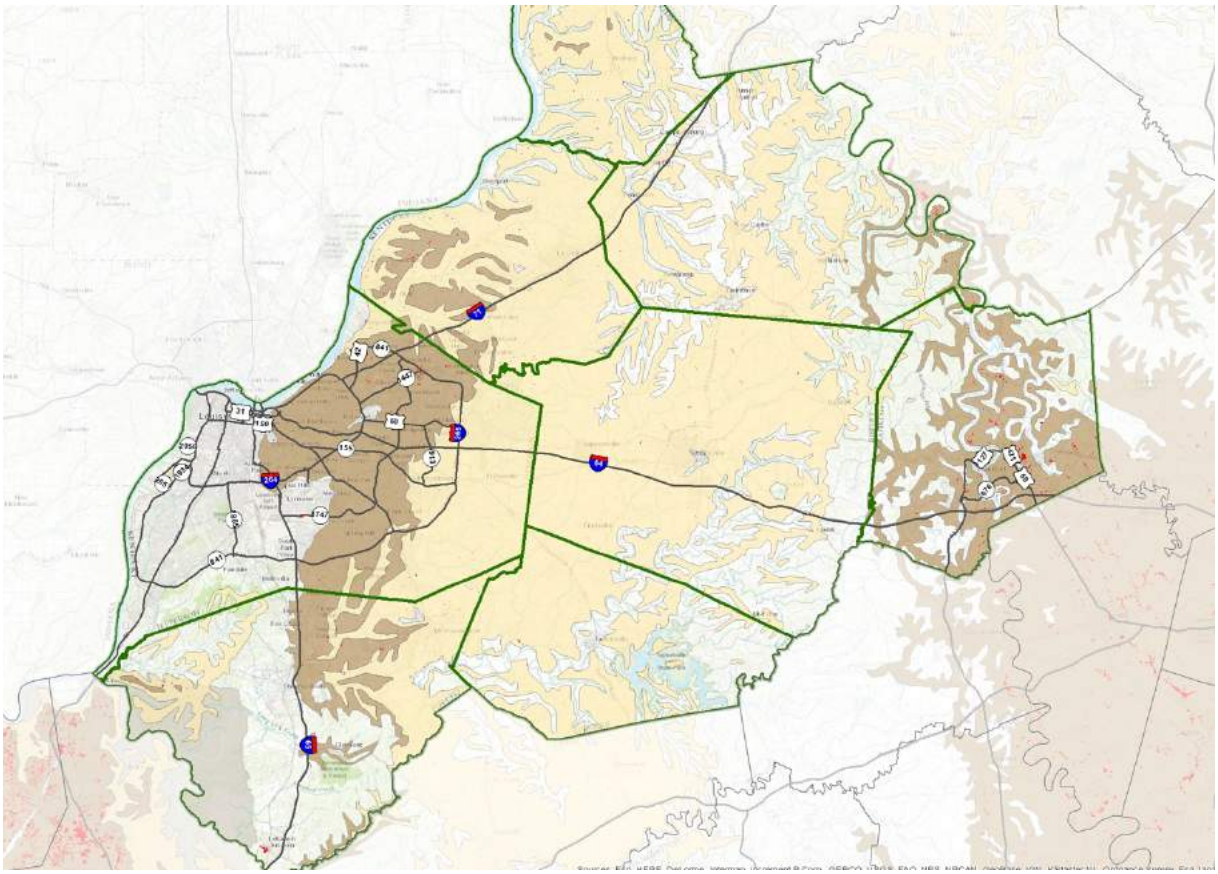

Figure 5-5. Karst potential and sinkholes in KYTC District 5

Other Meteorological Hazards

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

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

5.3.Workshop

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

5.3.1. Polling Results

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

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

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

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

5.3.2. Map Exercise

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

Table 5-3. District 5 NHS segments and flood

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

5.3.3. Workshop discussion

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

5.3.4. Roadways outside of the NHS that flood

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

5.3.5. Maintenance facilities flooding

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

5.3.6. Consensus workshop

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

Table 5-4. Results of District 5 consensus workshop

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

5.4.Results

5.4.1. Identification of most at vulnerable assets

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

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

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

5.4.2. Worst case scenario

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

6. District 6

6.1.KYTC District Overview

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

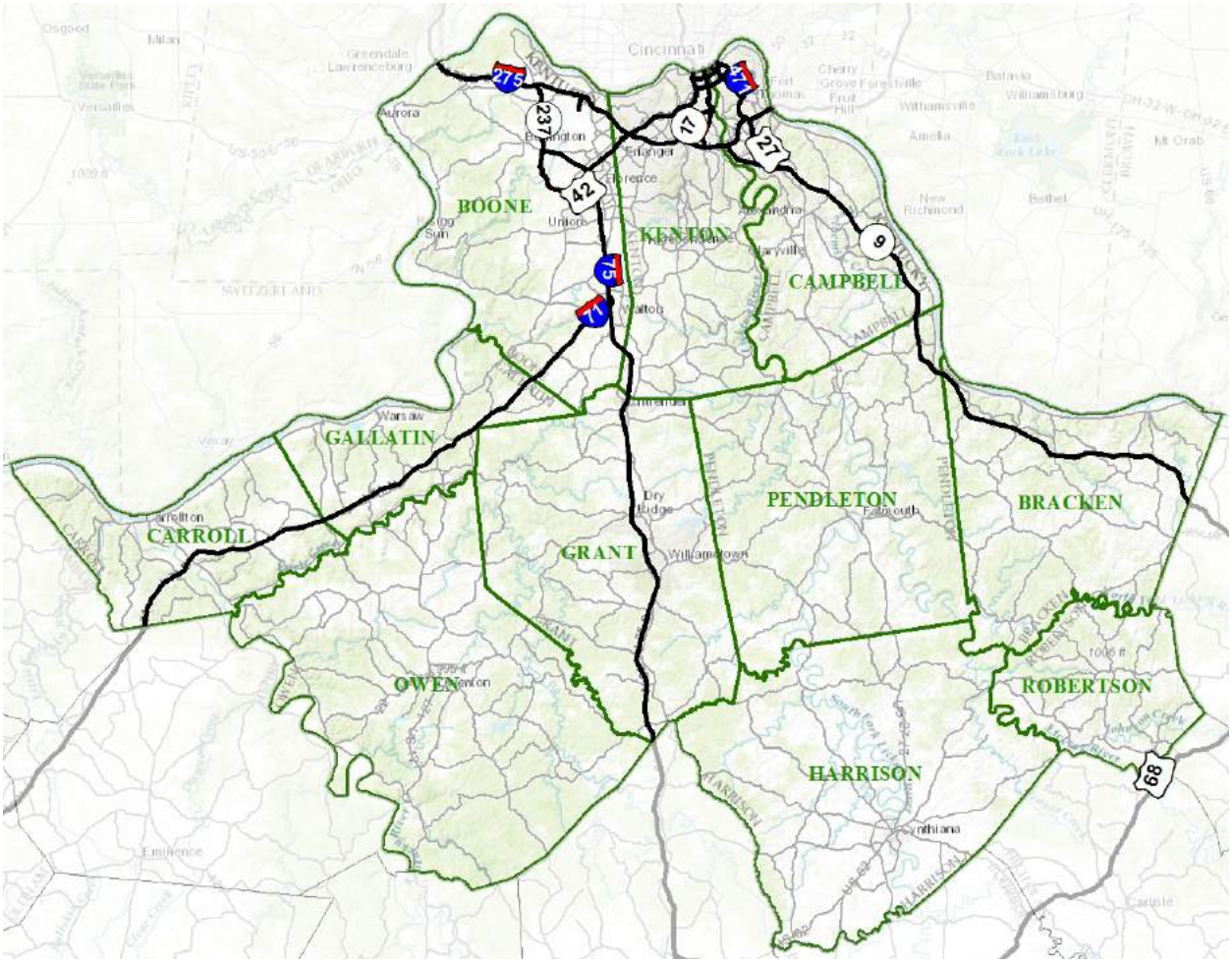

Figure 6-1. KYTC District 6 NHS

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

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

6.2.Hazards

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

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

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

6.2.1. Earthquake

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

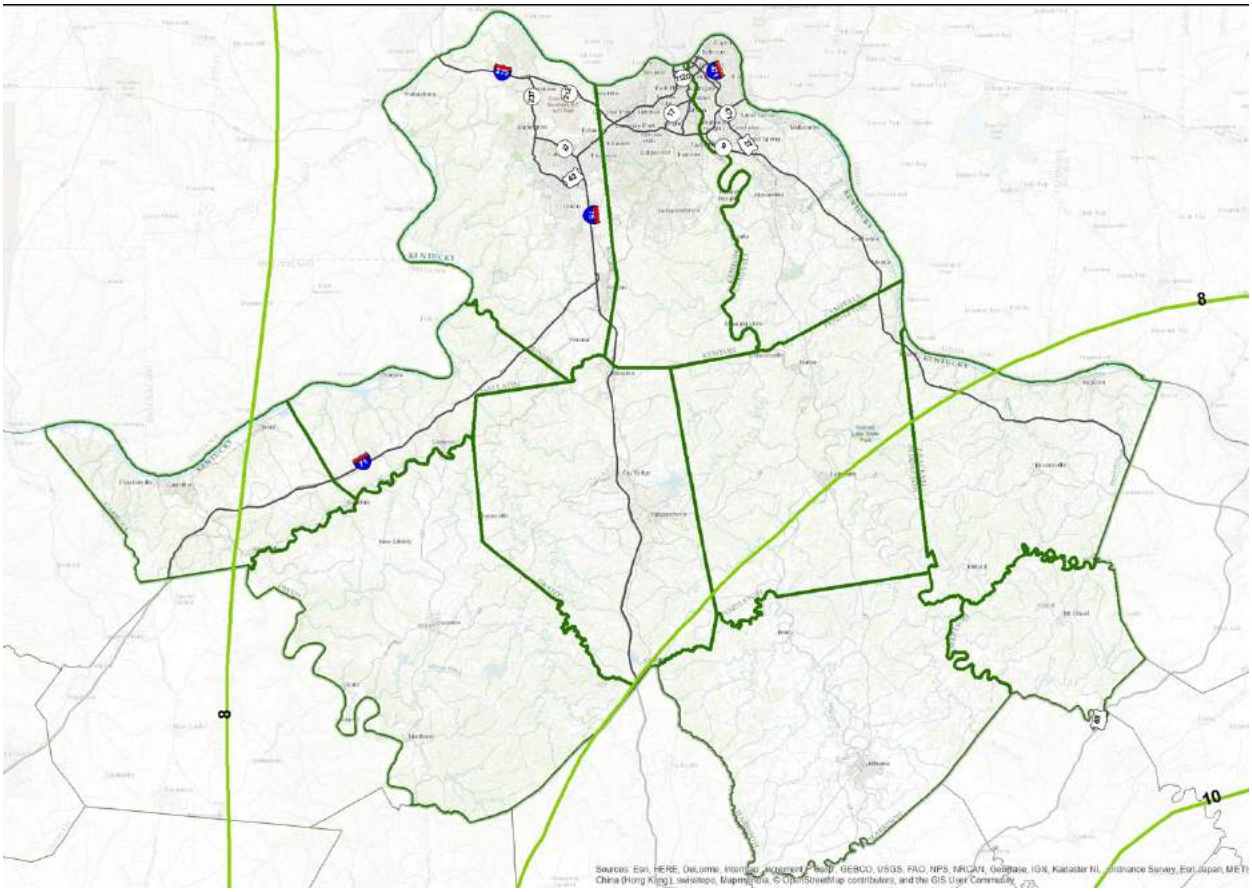

Figure 6-2. USGS PGA Zones in KYTC District 6

6.2.2. Flood

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

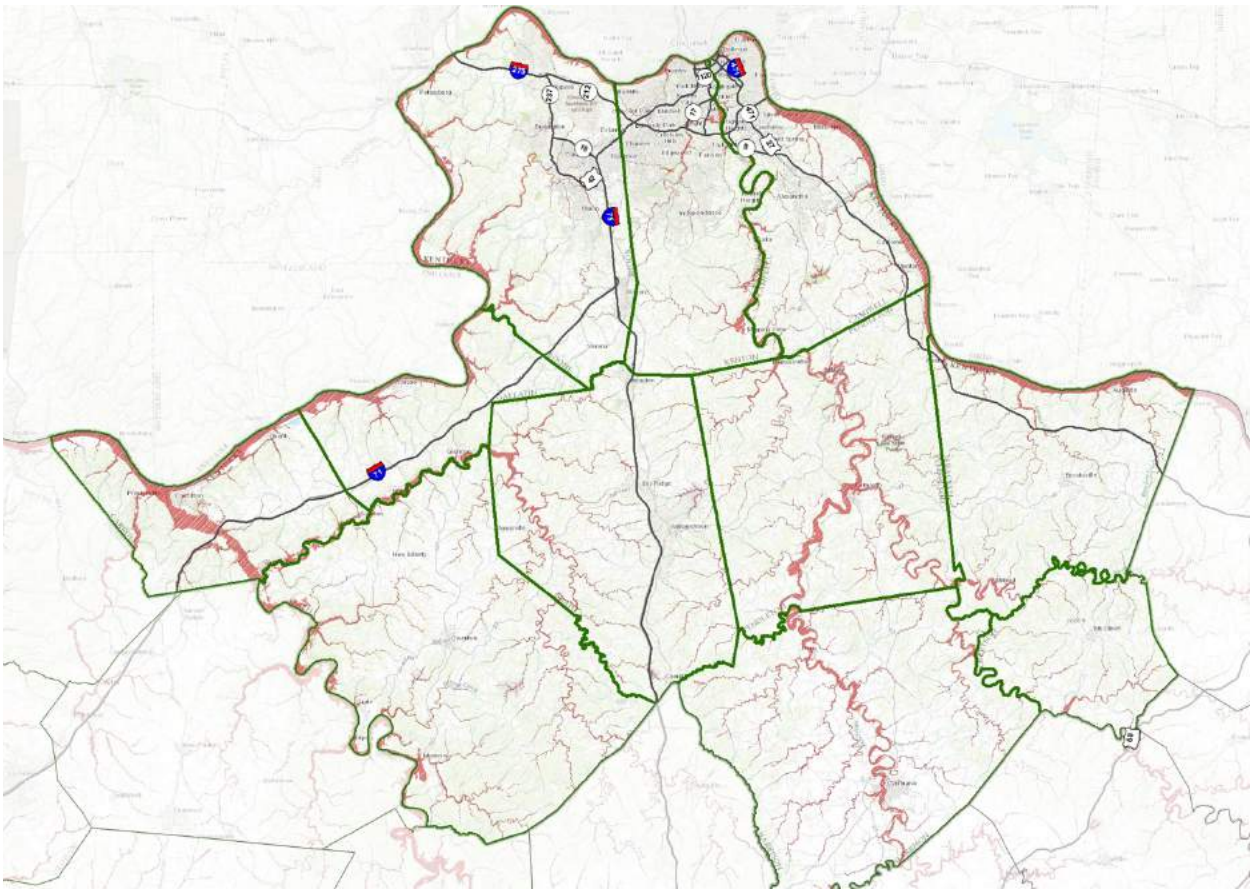

Figure 6-3. KYTC District 6; location of 100-year floodplain

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

6.2.3. Landslide

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

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

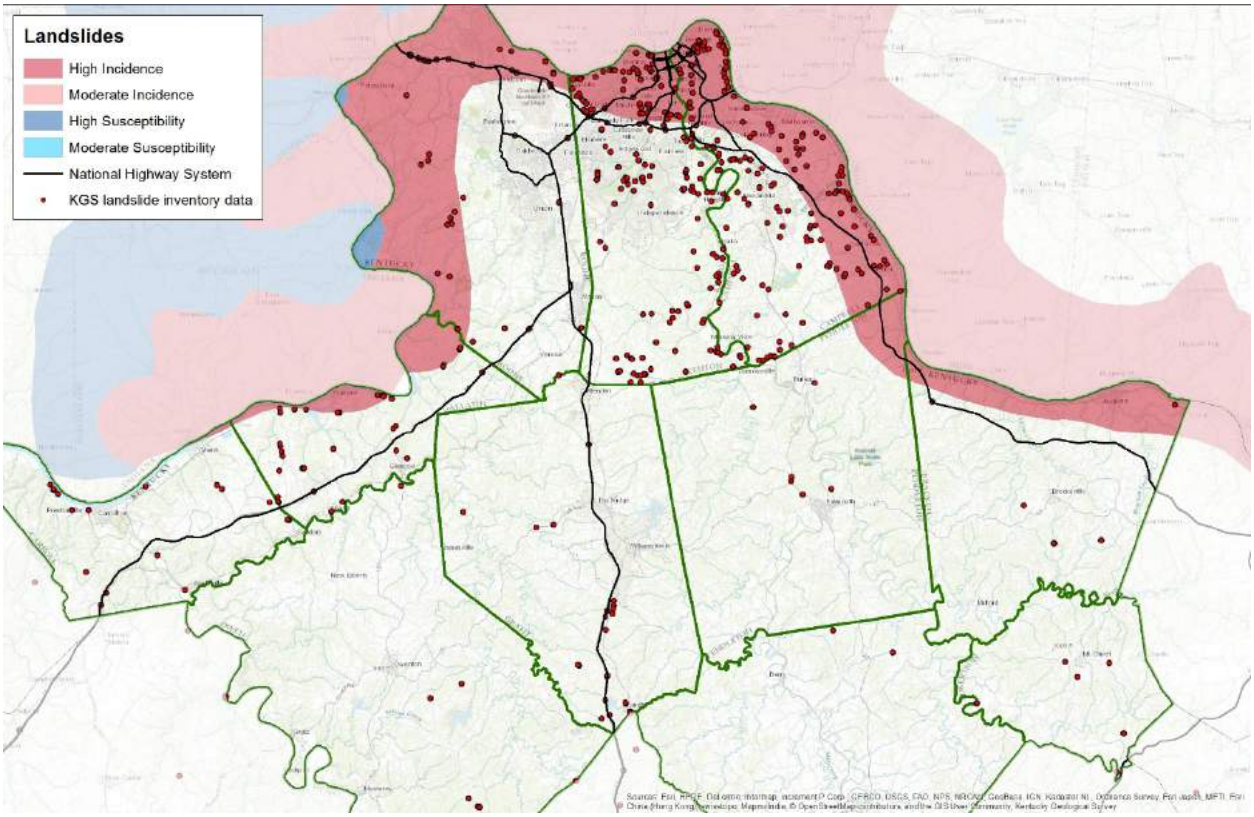

Figure 6-4.KYTC District 6 landslide susceptibility and incidences

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

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

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

6.2.4. Karst

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

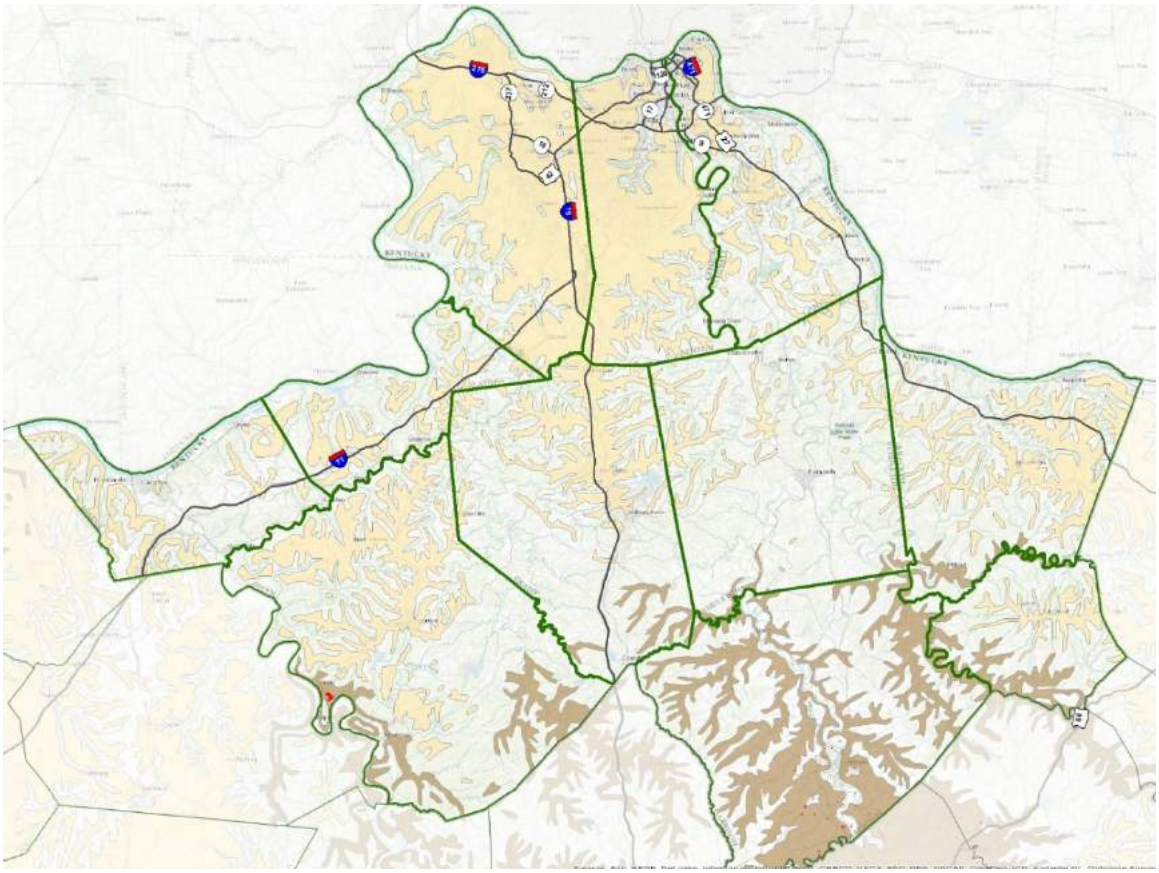

Figure 6-5. Karst potential and sinkholes in KYTC District 6

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

6.2.5. Other Meteorological Hazards

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

6.3.Workshop

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

6.3.1. Polling Results

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

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

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

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

6.3.2. Map Exercise

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

Table 6-3. District 6 NHS segments and flood

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

6.3.3. Workshop discussion

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

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

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

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

6.3.4. Roadways outside of the NHS that flood

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

6.3.5. Maintenance facilities flooding

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

6.3.6. Consensus workshop

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

Table 6-4. Results of District 6 consensus workshop

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

6.4.Results

6.4.1. Identification of most at vulnerable assets

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

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

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

6.4.2. Worst case scenario

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

7. KYTC District 7

7.1.District Overview

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

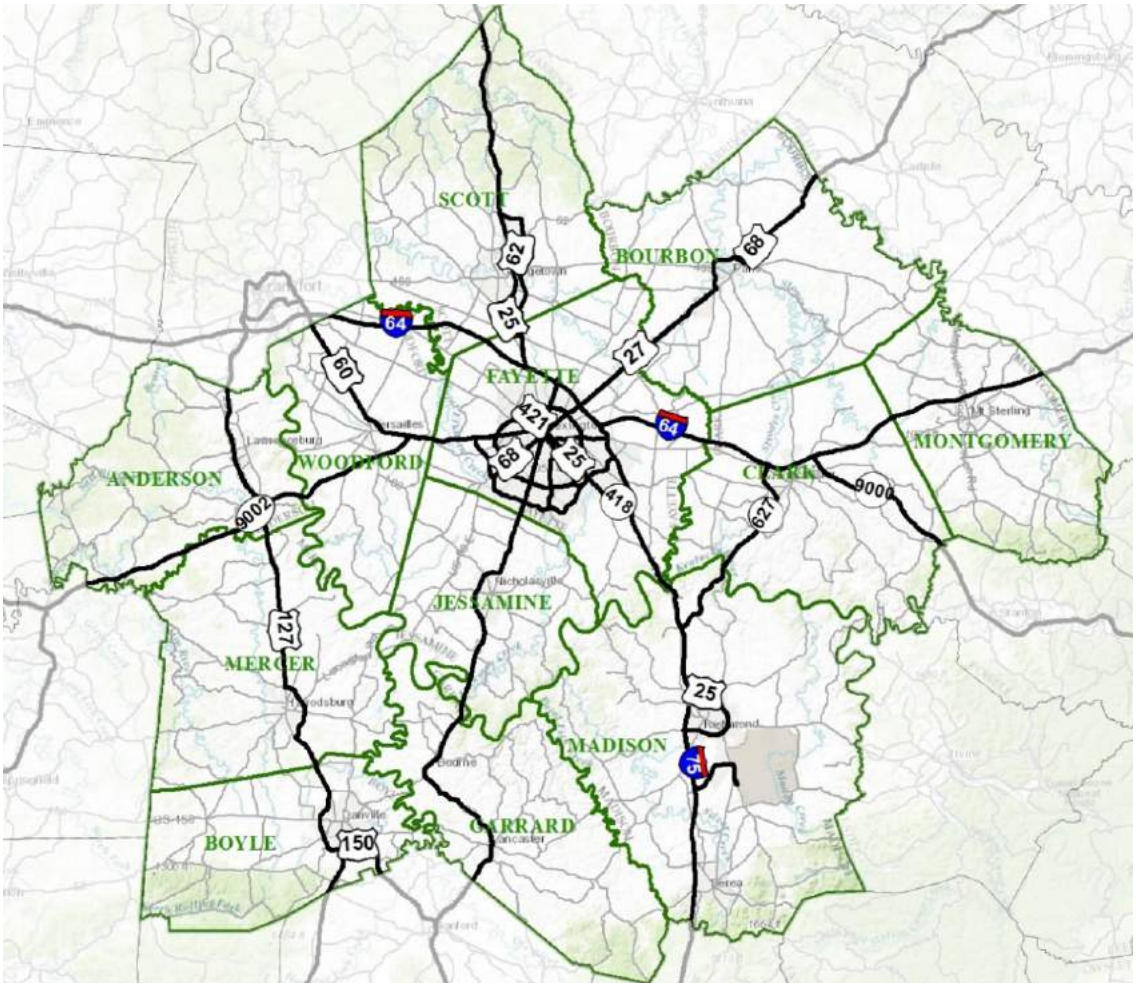

Figure 7-1. KYTC District 7 NHS

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

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

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

7.2.Hazards

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

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

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

7.2.1. Earthquake

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

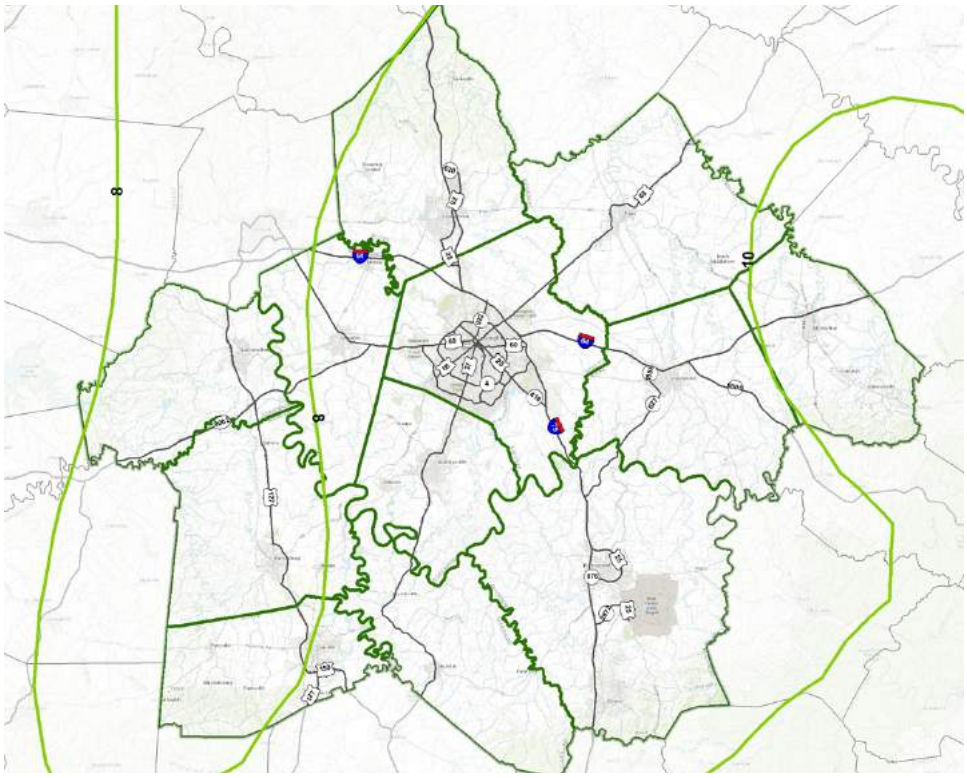

Figure 7-2.USGS PGA Zones in KYTC District 7

7.2.2. Flood

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

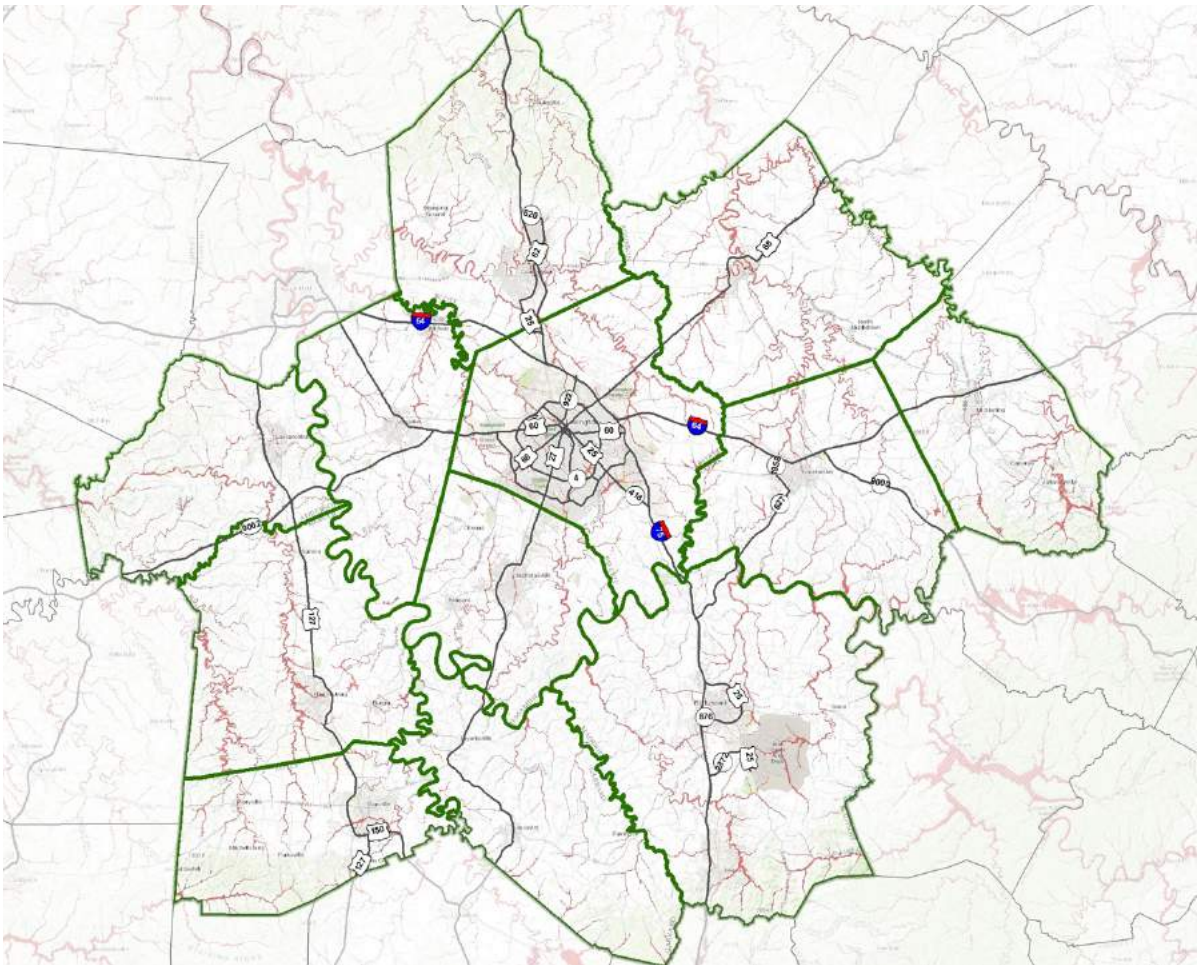

Figure 7-3. KYTC District 7; location of 100-year floodplain

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

7.2.3. Landslide

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

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

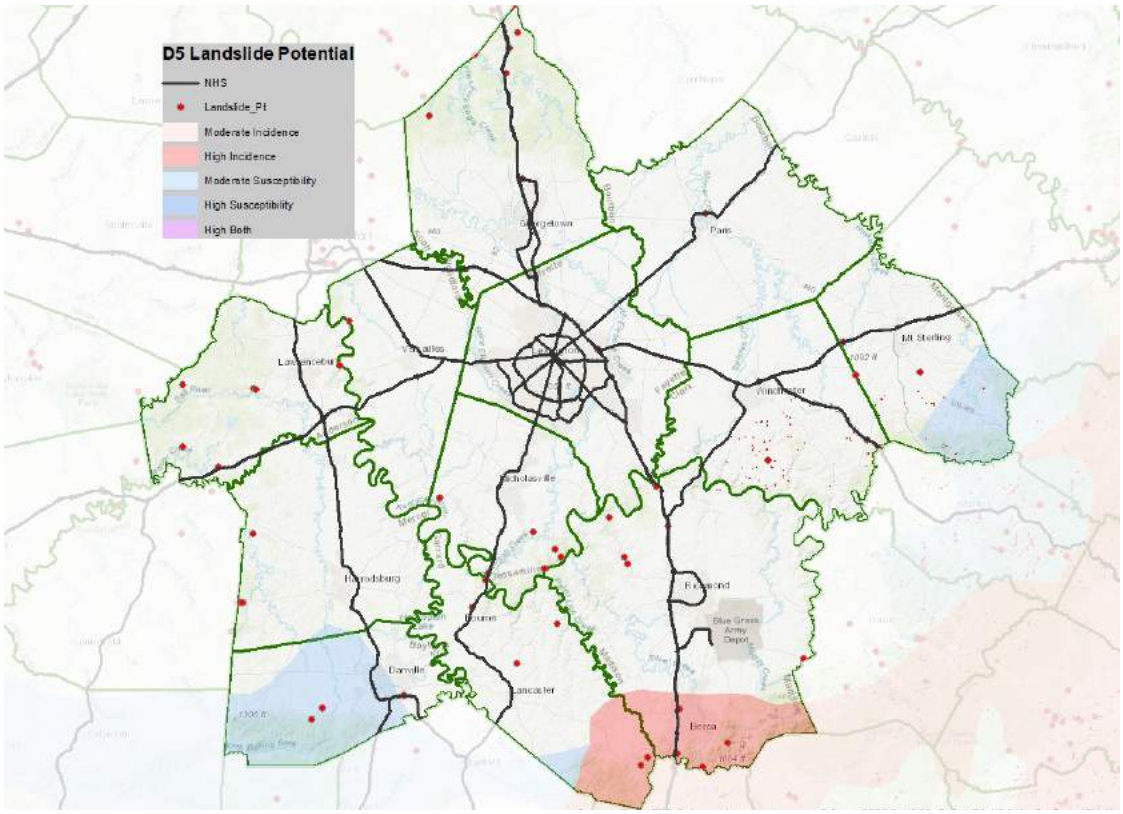

Figure 7-4.KYTC District 7 landslide susceptibility and incidences

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

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

7.2.4. Karst

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

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

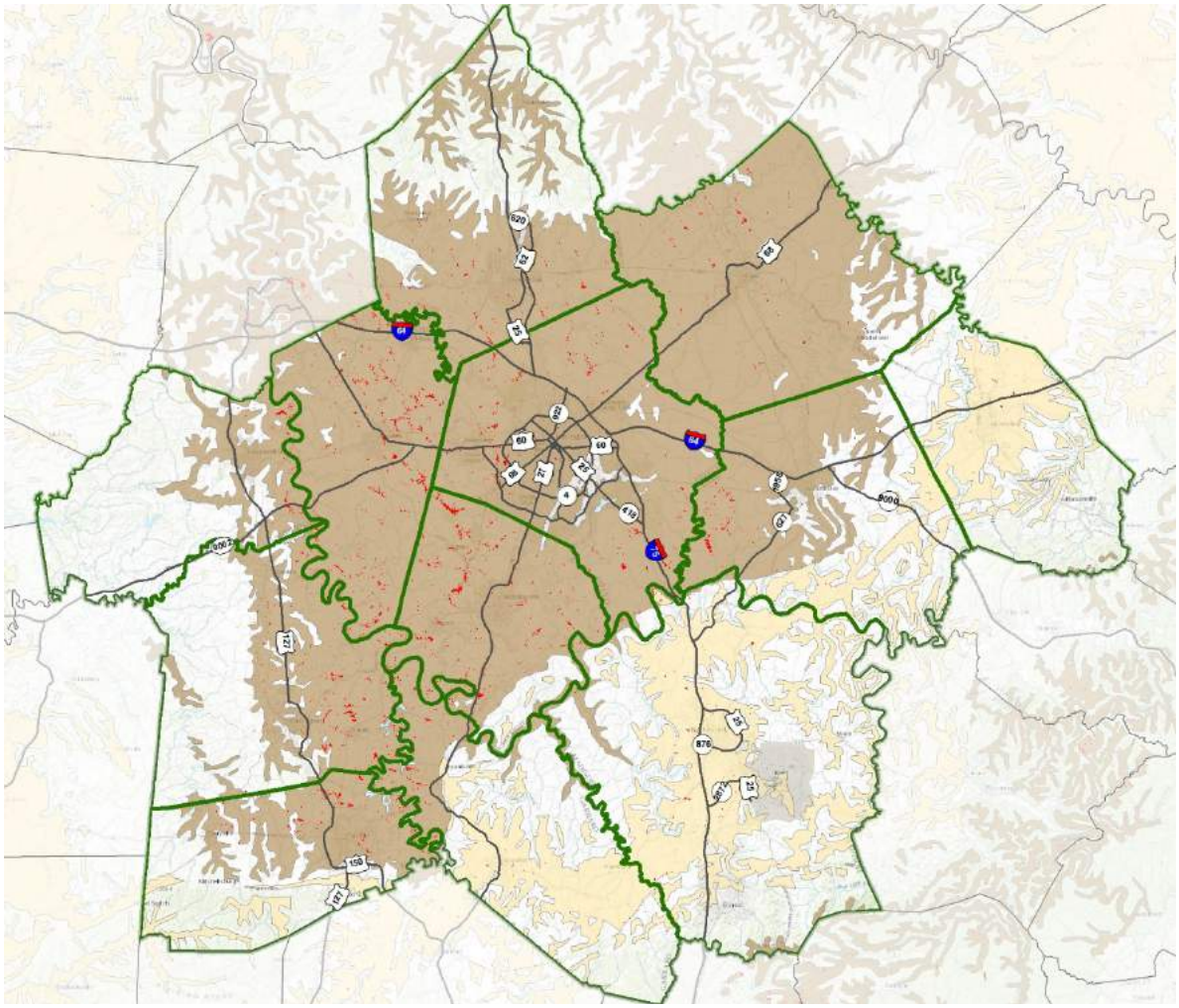

Figure 7-5. Karst potential and sinkholes in KYTC District 7

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

7.2.5. Other Meteorological Hazards

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

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

7.3.Workshop

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

7.3.1. Polling Results

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

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

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

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

7.3.2. Map Exercise

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

Table 7-3. District 7 NHS segments and flood

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

7.3.3. Workshop discussion

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

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

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

7.3.4. Roadways outside of the NHS that flood

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

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

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

7.3.5. Maintenance facilities flooding

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

7.3.6. Consensus workshop

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

Table 7-4. Results of District 7 consensus workshop

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

7.4.Results

7.4.1. Identification of most at vulnerable assets

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

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

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

7.4.2. Worst case scenario

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

8. KYTC District 8

8.1.District Overview

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

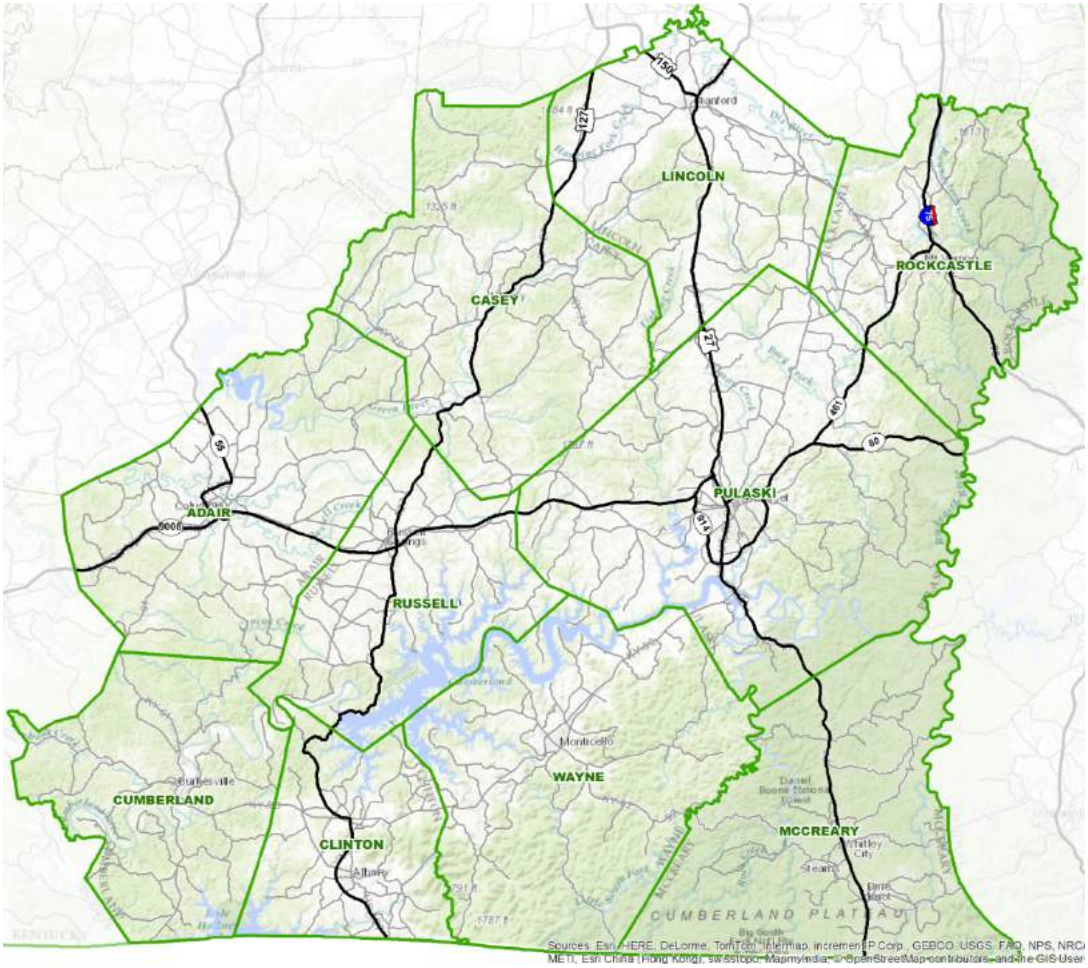

Figure 8-1. KYTC District 8 NHS

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

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

8.2.Hazards

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

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

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

8.2.1. Earthquake

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

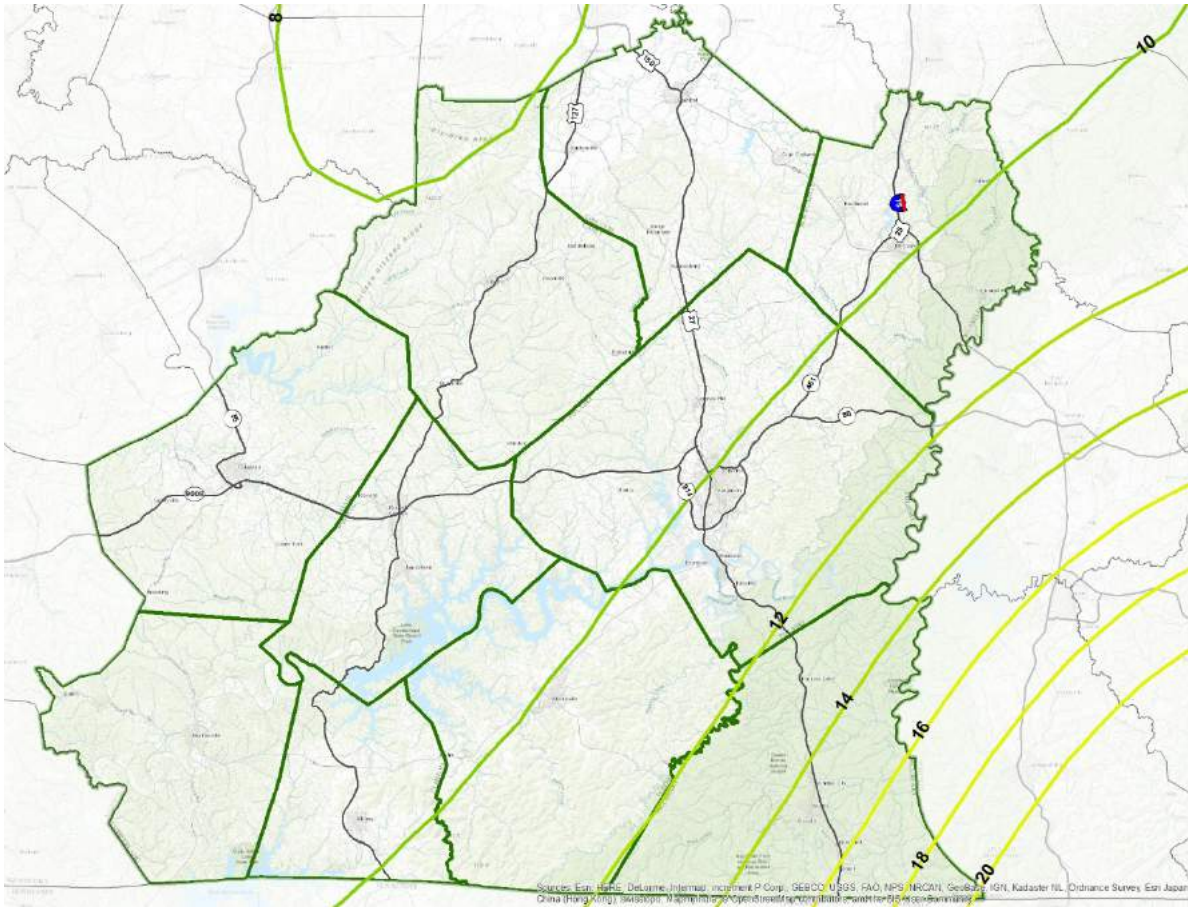

Figure 8-2. USGS PGA Zones in KYTC District 8

8.2.2. Flood

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

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

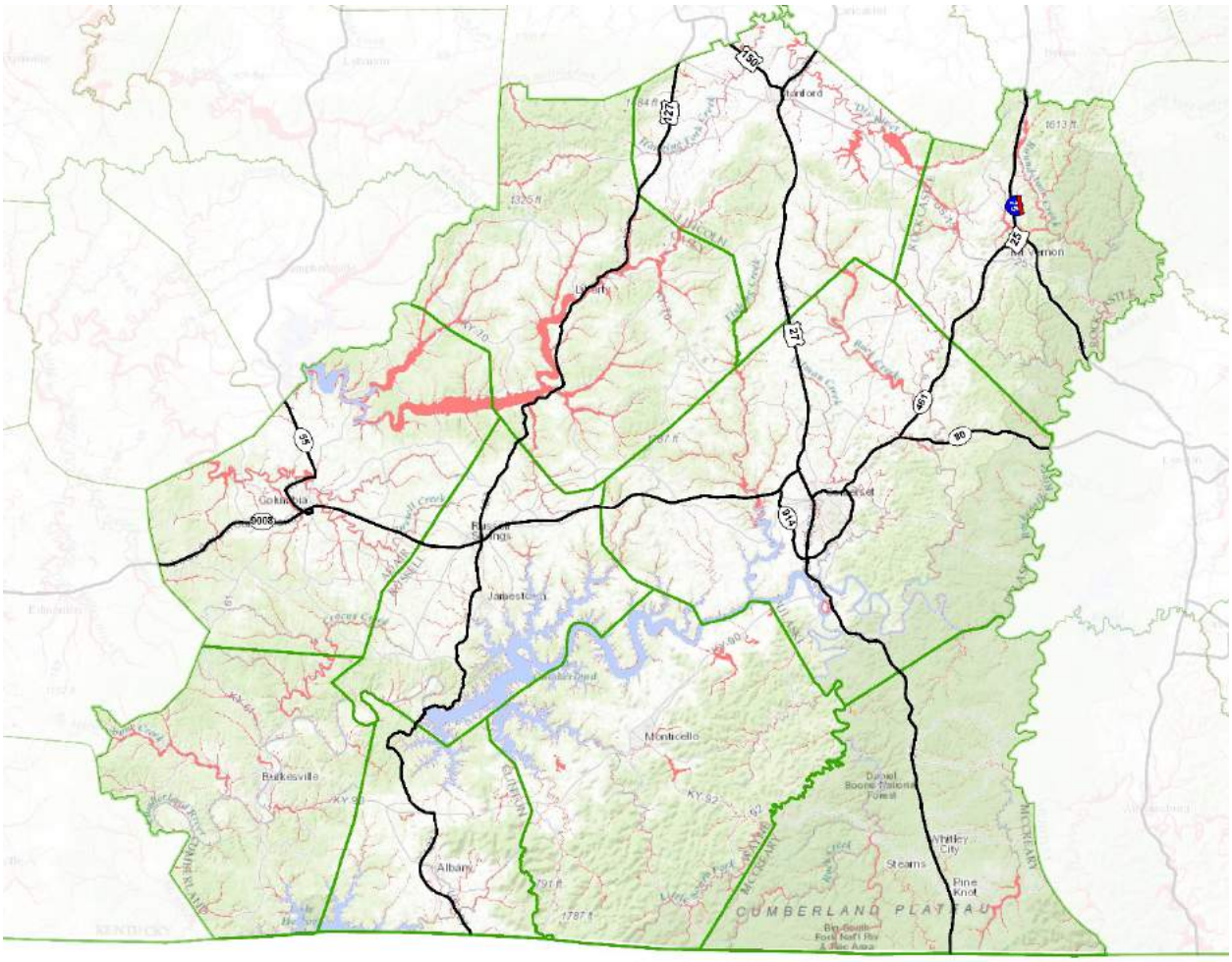

Figure 8-3. KYTC District 8; location of 100-year floodplain

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

8.2.3. Landslide

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

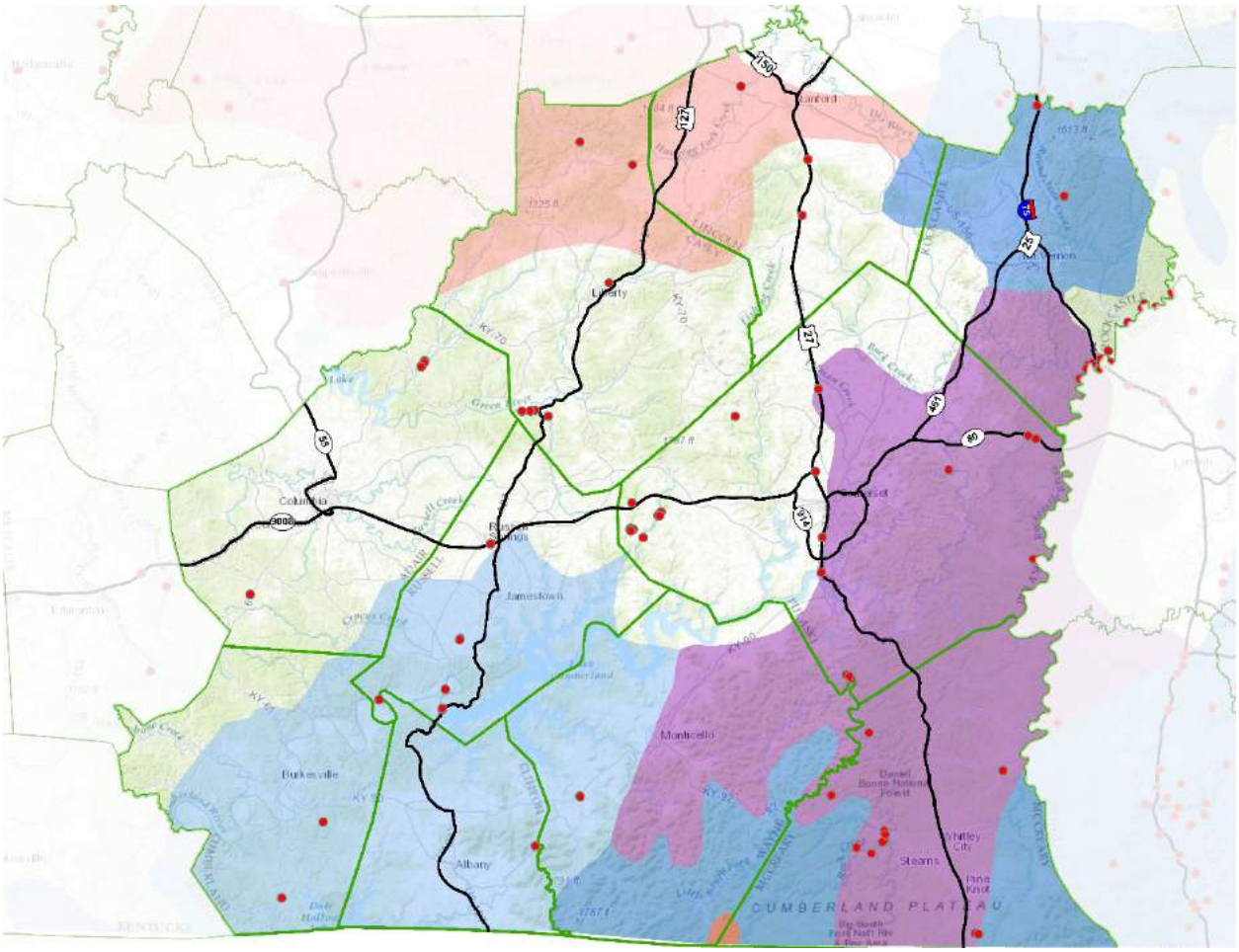

Figure 8-4. KYTC District 8 landslide incidence and susceptibility

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

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

8.2.4. Karst

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

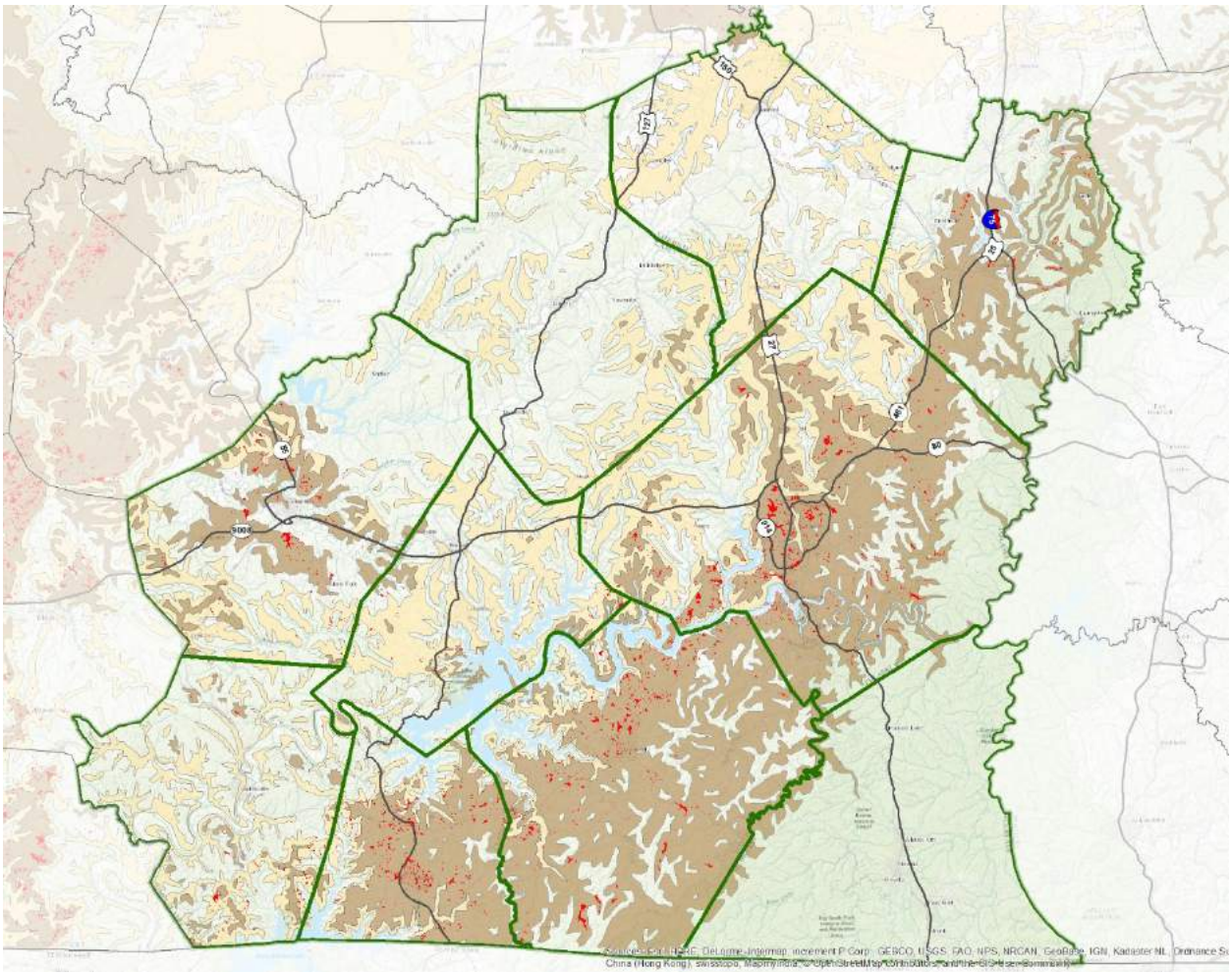

Figure 8-5. Karst potential and sinkholes in KYTC District 8

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

8.2.5. Other Meteorological Hazards

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

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

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

8.3.Workshop

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

8.3.1. Polling Results

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

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

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

8.3.2. Map Exercise

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

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

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

8.3.3. Workshop discussion

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

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

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

8.3.4. Roadways outside of the NHS that flood

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

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

8.3.5. Maintenance facilities flooding

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

8.3.6. Consensus workshop

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

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

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

8.4.Results

8.4.1. Identification of most at vulnerable assets

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

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

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

8.4.2. Worst case scenario

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

9. KYTC District 9

9.1.District Overview

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

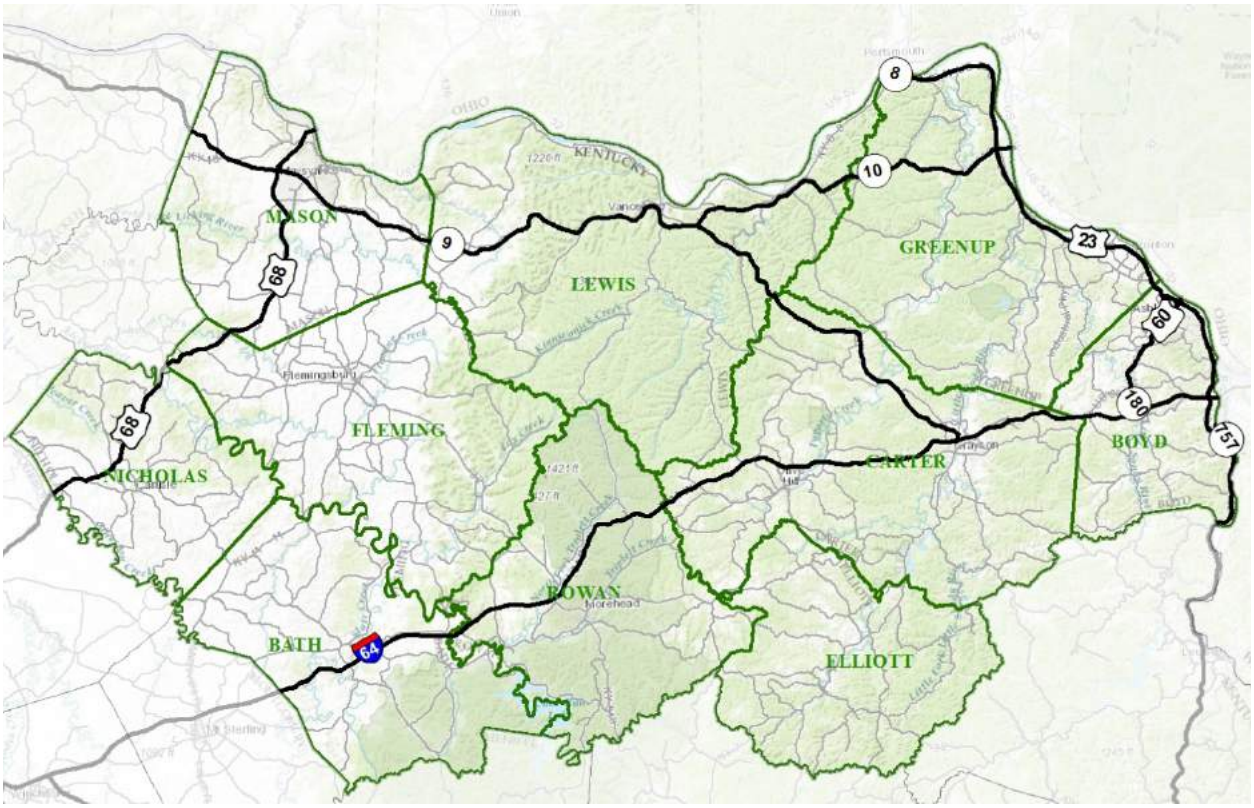

Figure 9-1.KYTC District 9 NHS

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

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

9.2.Hazards

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

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

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

9.2.1. Earthquake

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

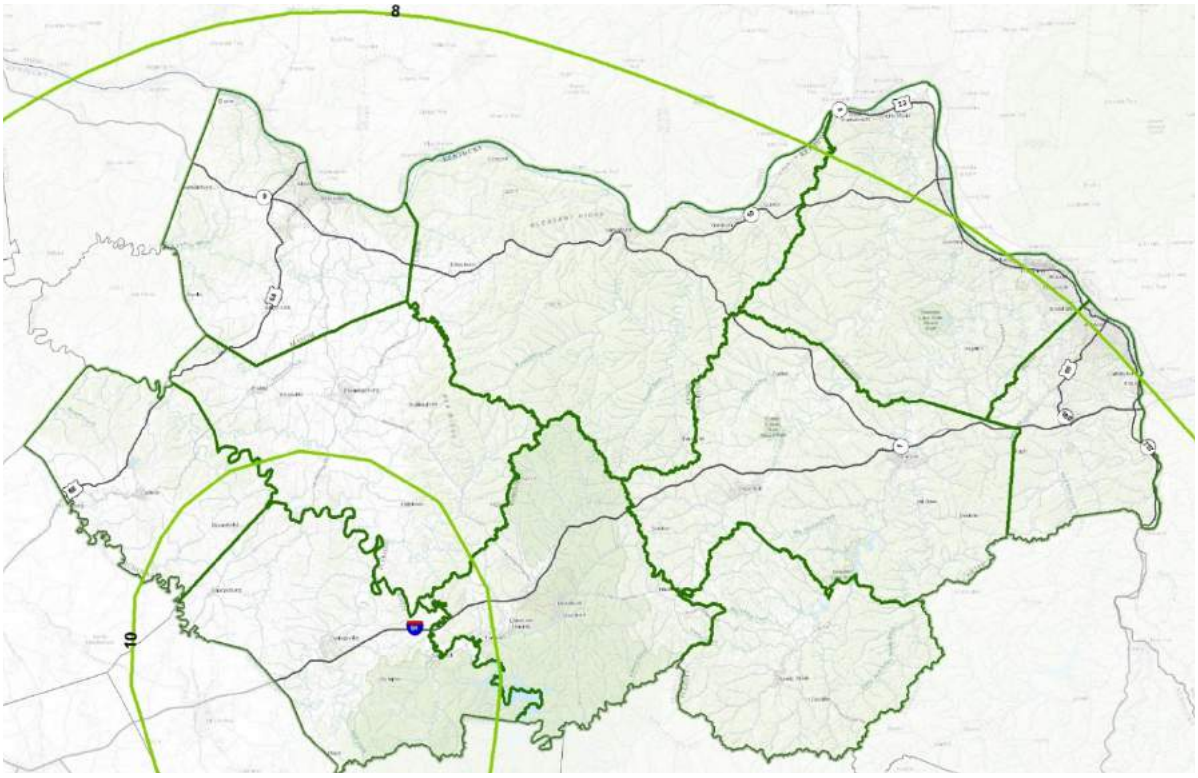

Figure 9-2. PGA Zones in KYTC District 9

9.2.2. Flood

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

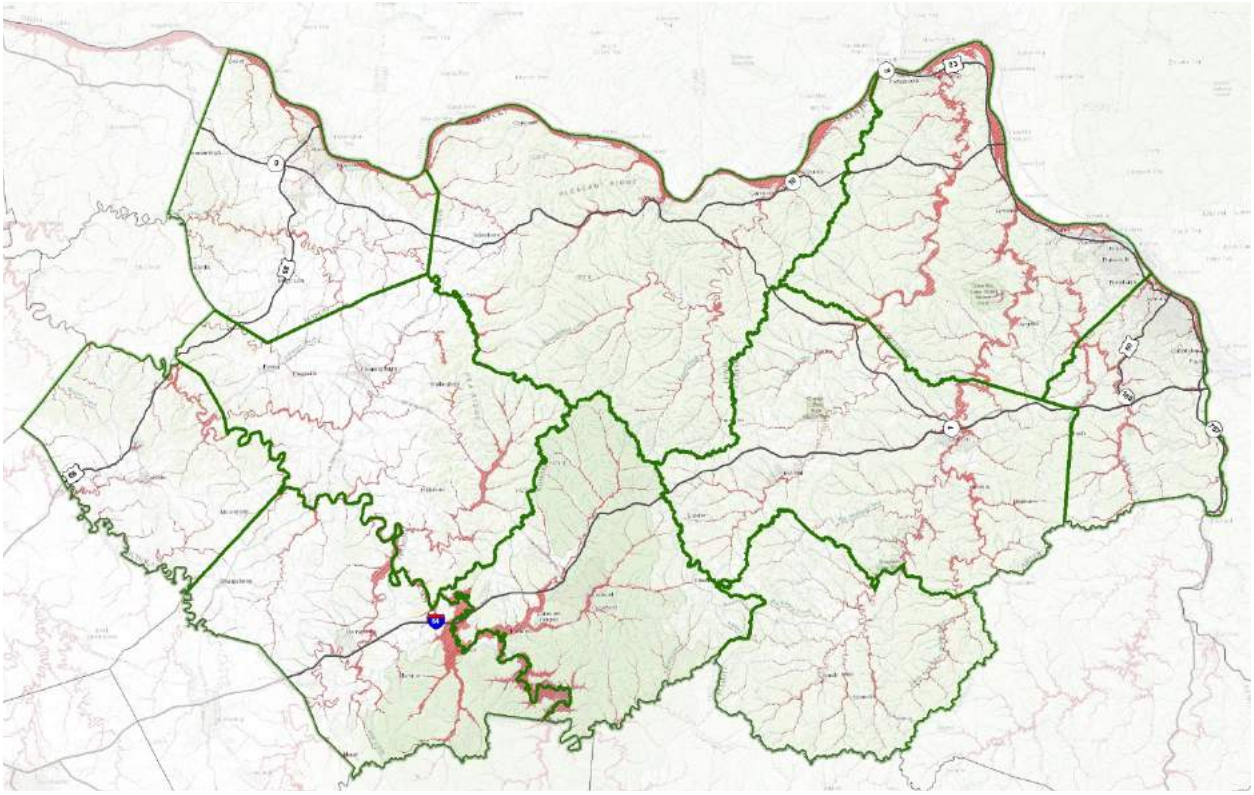

Figure 9-3. KYTC District 9; location of 100-year floodplain

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

9.2.3. Landslide

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

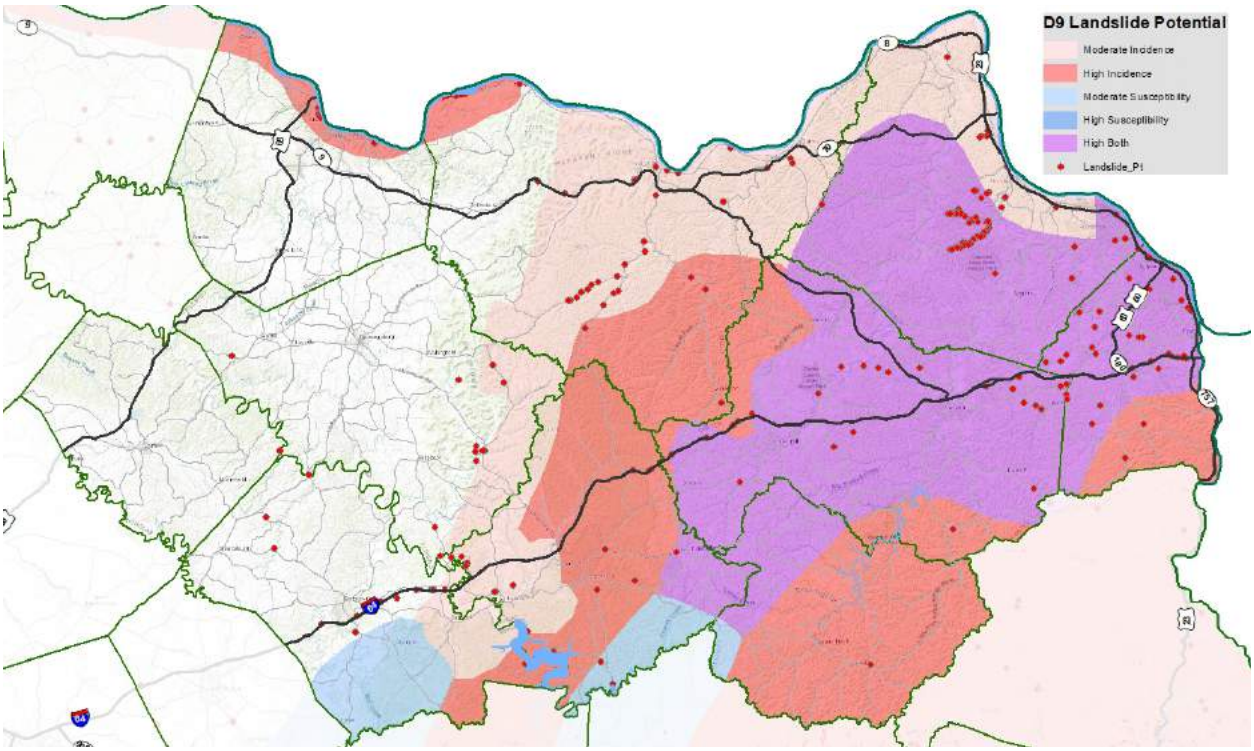

Figure 9-4. Landslide incidence and susceptibility in KYTC District 9

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

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

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

9.2.4. Karst

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

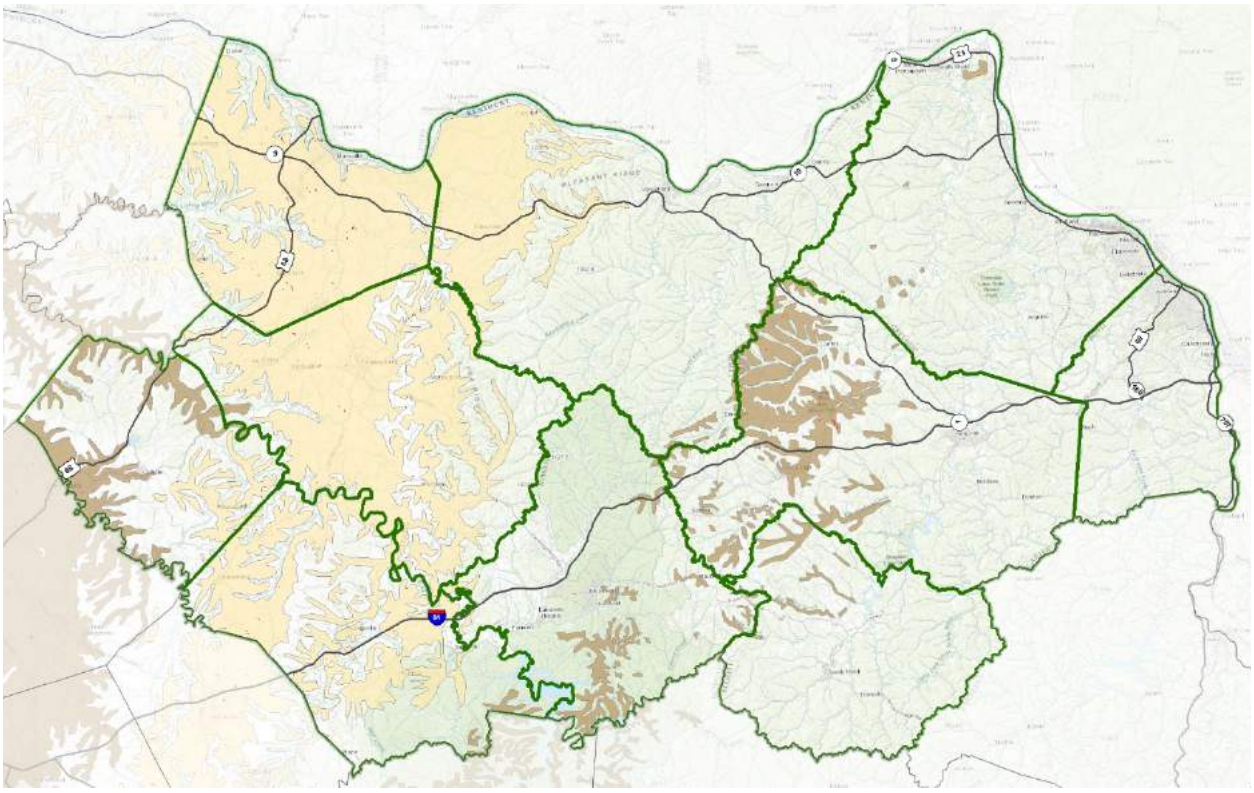

Figure 9-5. Karst potential and sinkholes in KYTC District 9

9.2.5. Other Meteorological Hazards

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

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

9.3.Workshop

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

9.3.1. Polling Results

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

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

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

9.3.2. Map Exercise

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

Table 9-3. District 9 NHS segments and flood

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

9.3.3. Workshop discussion

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

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

9.3.4. Roadways outside of the NHS that flood

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

9.3.5. Maintenance facilities flooding

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

9.3.6. Consensus workshop

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

Table 9-4. Results of District 9 consensus workshop

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

9.4.Results

9.4.1. Identification of most at vulnerable assets

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

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

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

9.4.2. Worst Case Scenario

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

10. District 10

10.1. District Overview

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

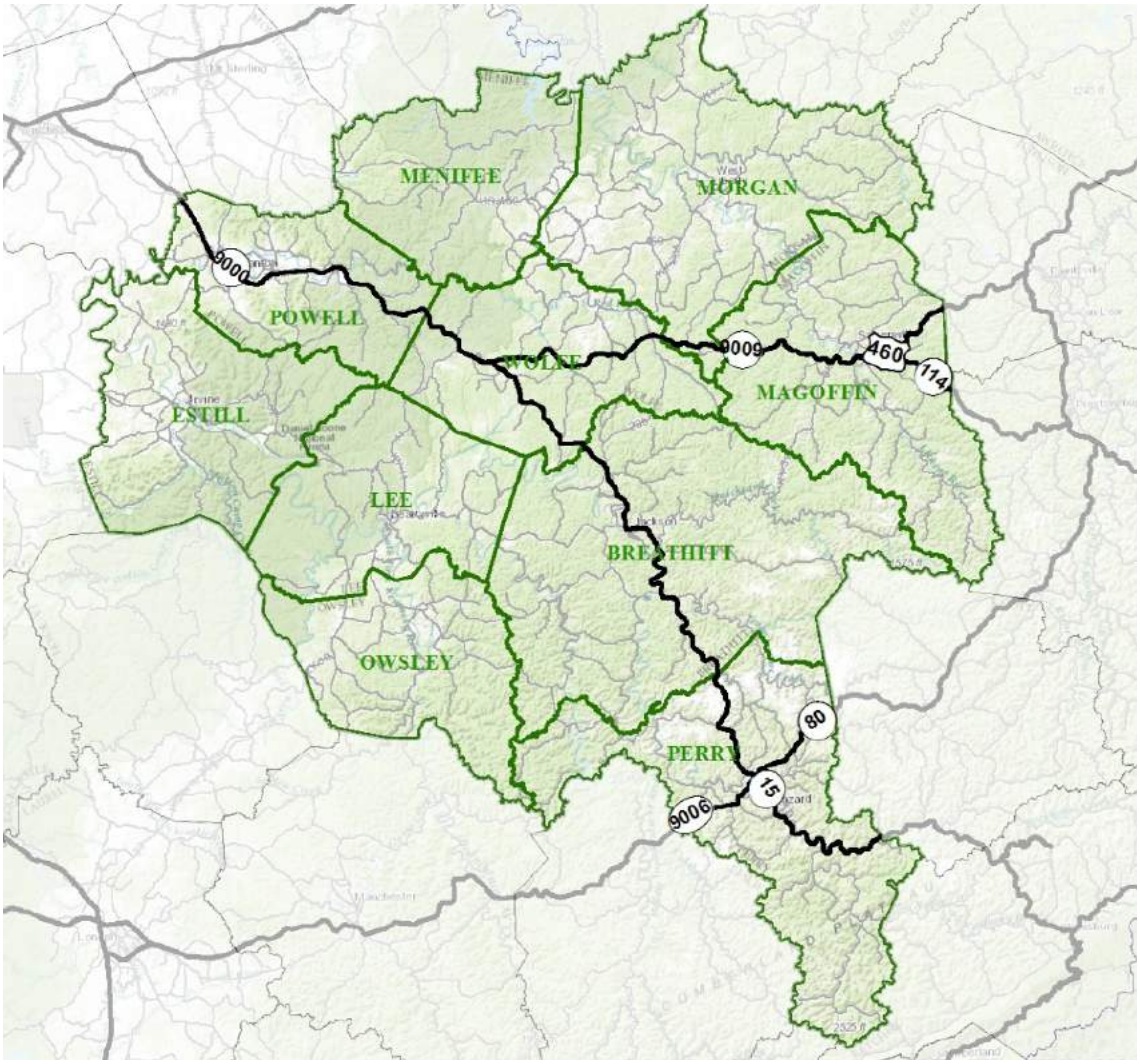

Figure 10-1.KYTC District 10 NHS

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

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

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

10.2. Hazards

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

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

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

10.2.1. Earthquake

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

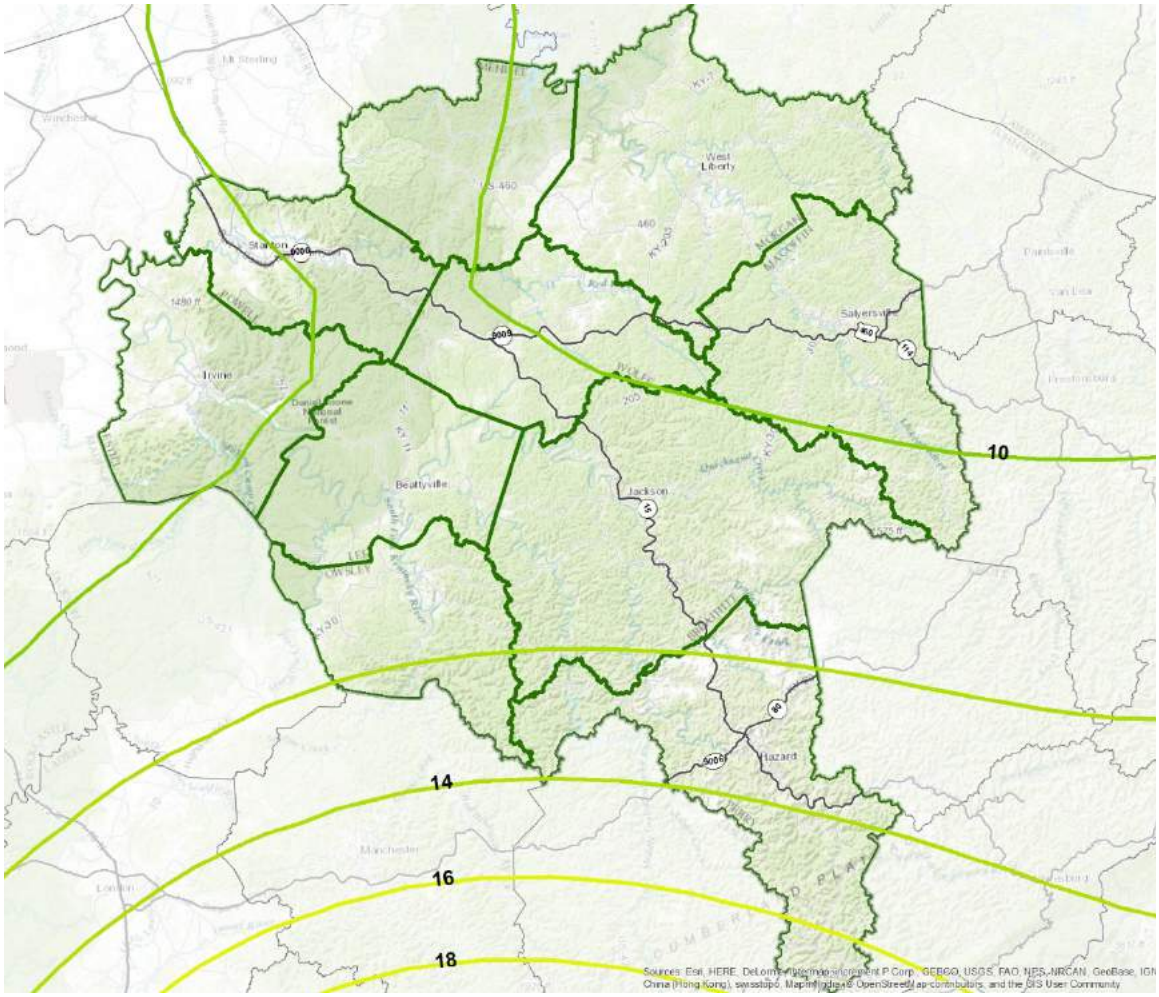

Figure 10-2. USGS PGA Zones in KYTC District 10

10.2.2. Flood

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

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

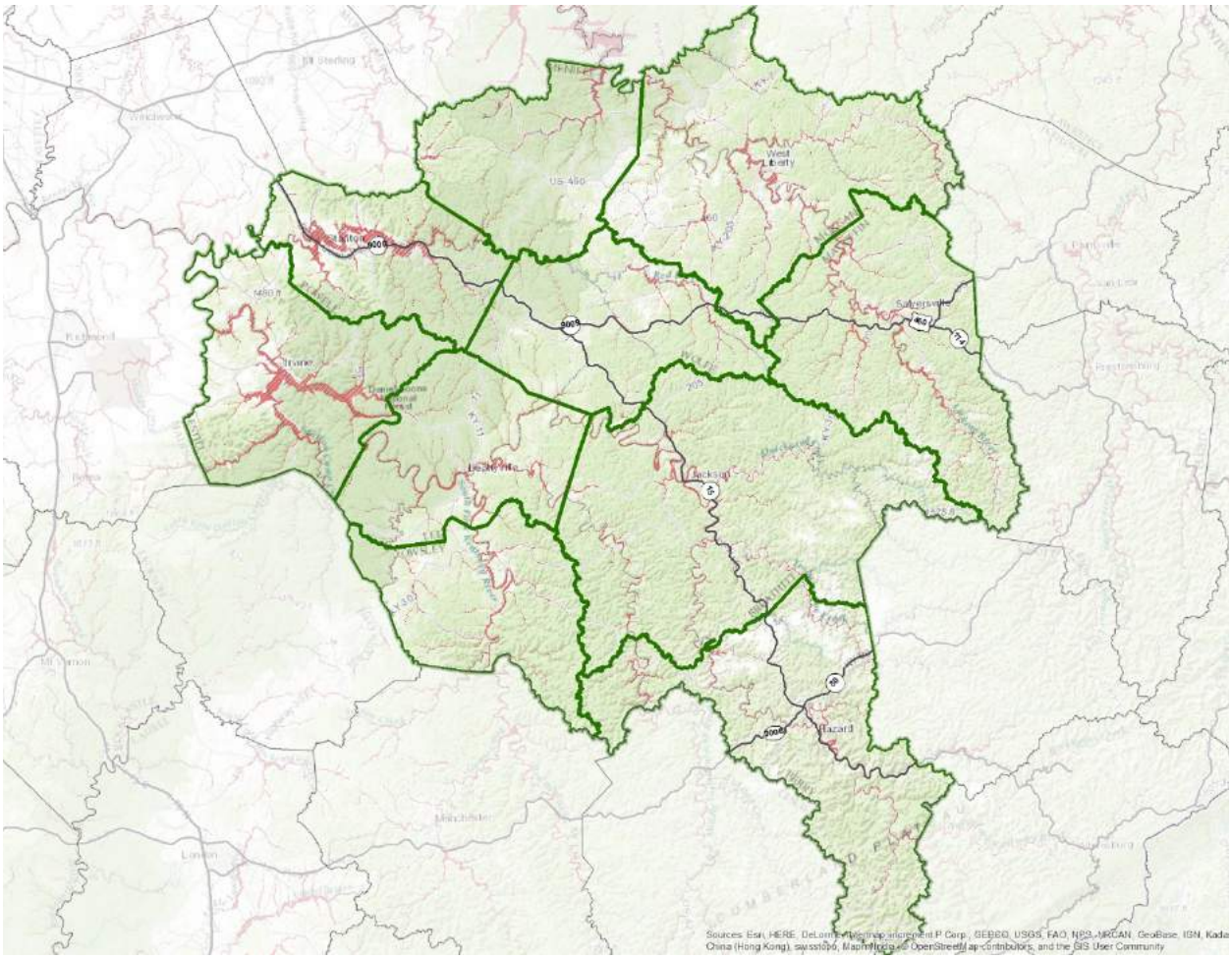

Figure 10-3. KYTC District 10; location of 100-year floodplain

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

10.2.3. Landslide

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

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

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

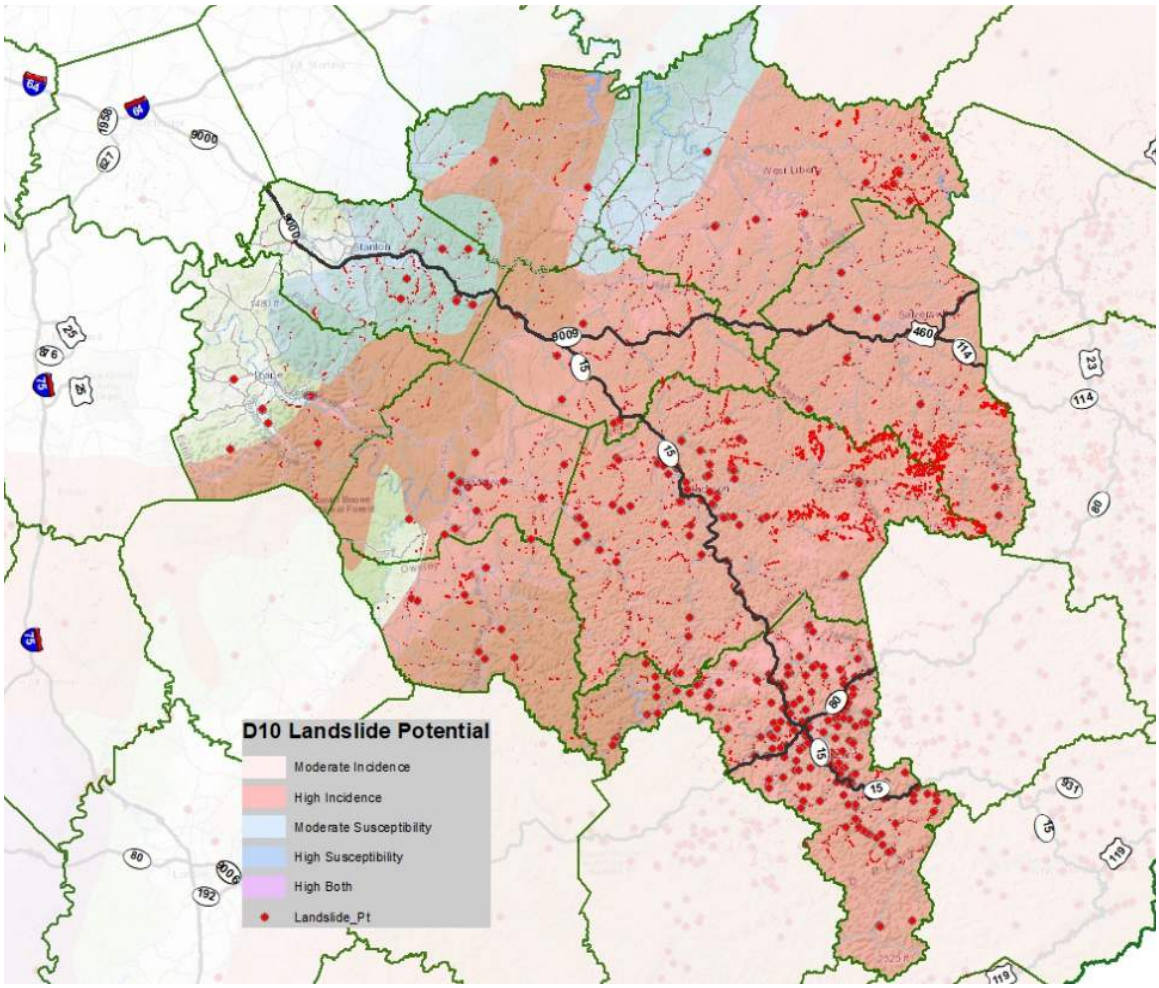

Figure 10-4. Landslide incidence and susceptibility in KYTC District 10

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

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

10.2.4. Karst

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

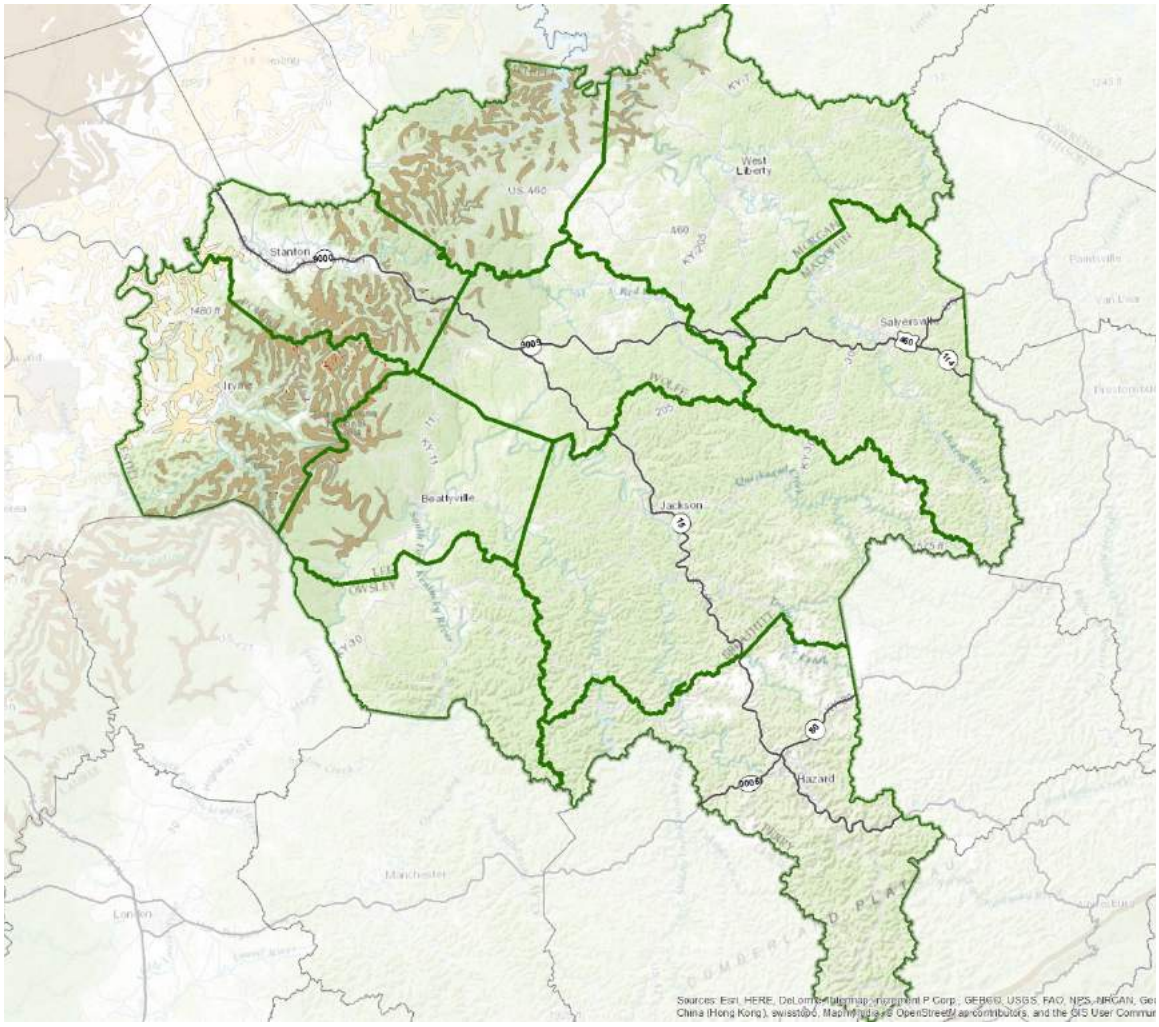

Figure 10-5. Karst potential and sinkholes in KYTC District 10

10.2.5. Other Meteorological Hazards

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

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

10.3. Workshop

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

10.3.1. Polling Results

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

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

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

10.3.2. Map Exercise

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

Table 10-3. District 10 NHS segments and flood

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

10.3.3. Workshop discussion

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

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

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

10.3.4. Roadways outside of the NHS that flood

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

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

10.3.5. Maintenance facilities flooding

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

10.3.6. Consensus workshop

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

Table 10-4. Results of District 10 consensus workshop

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

10.4. Results

10.4.1. Identification of most at vulnerable assets

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

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

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

10.4.2. Worst case scenario

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

11. KYTC District 11

11.1. District Overview

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

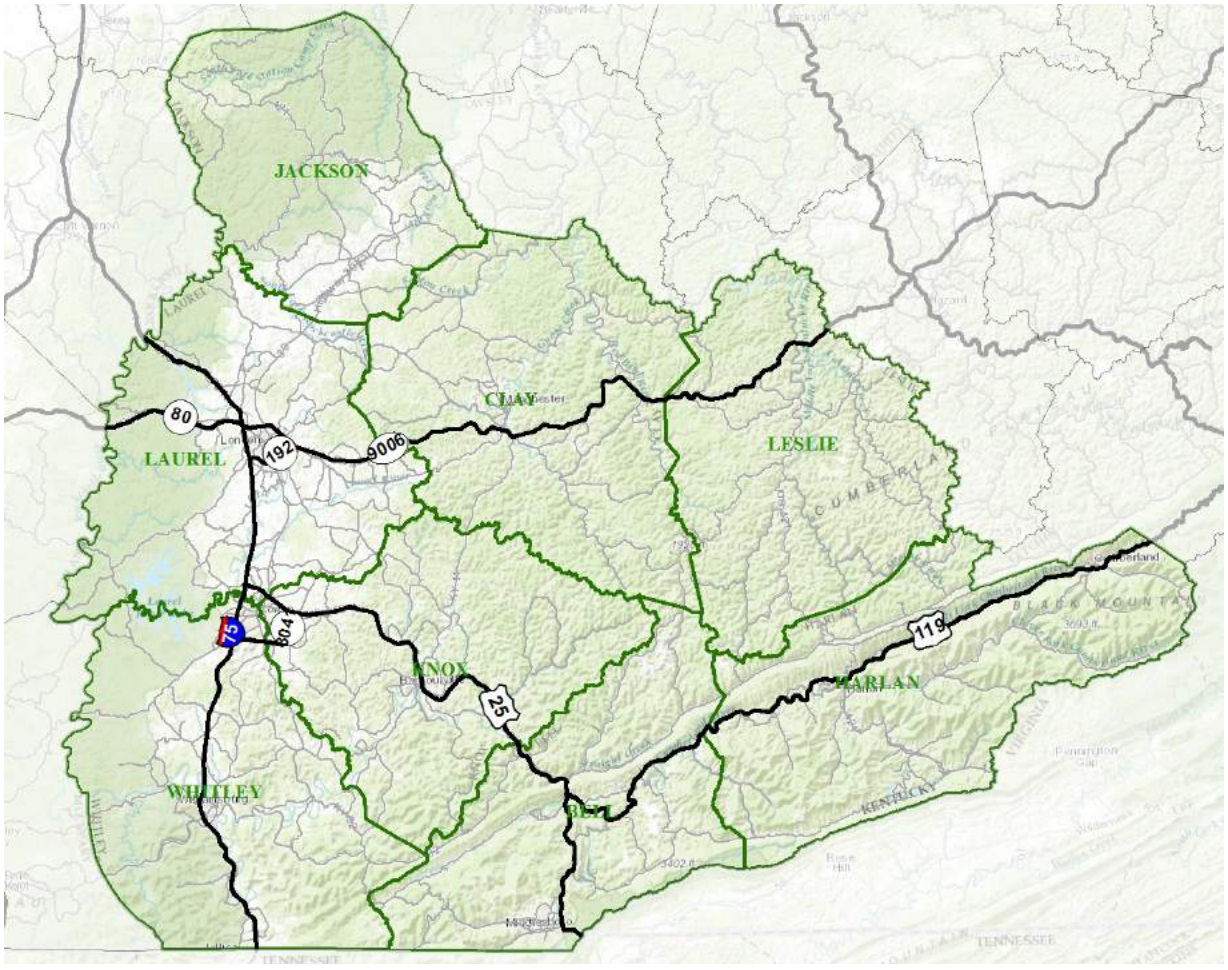

Figure 11-1. KYTC District 11 NHS

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

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

11.2. Hazards

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

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

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

11.2.1. Earthquake

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

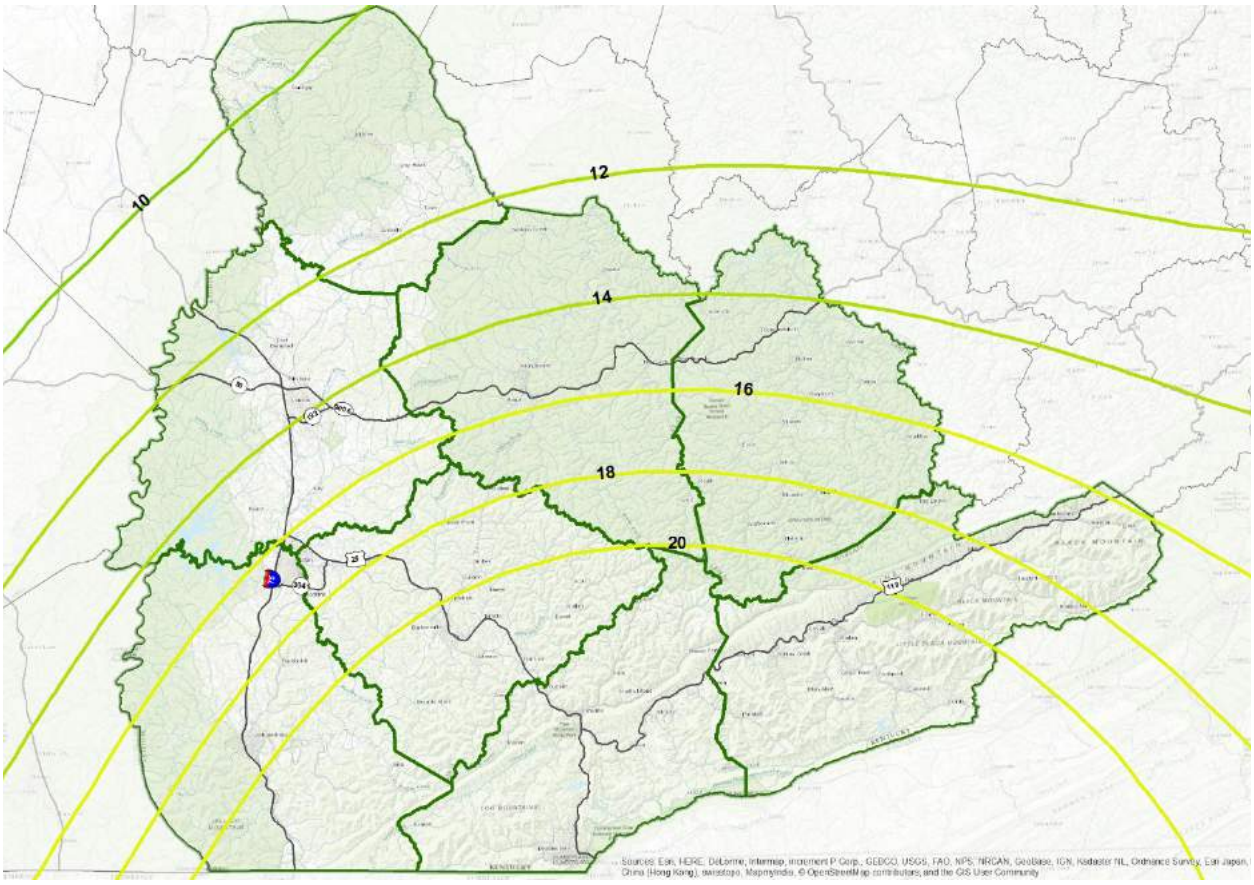

Figure 11-2. USGS PGA Zones in KYTC District 11

11.2.2. Flood

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

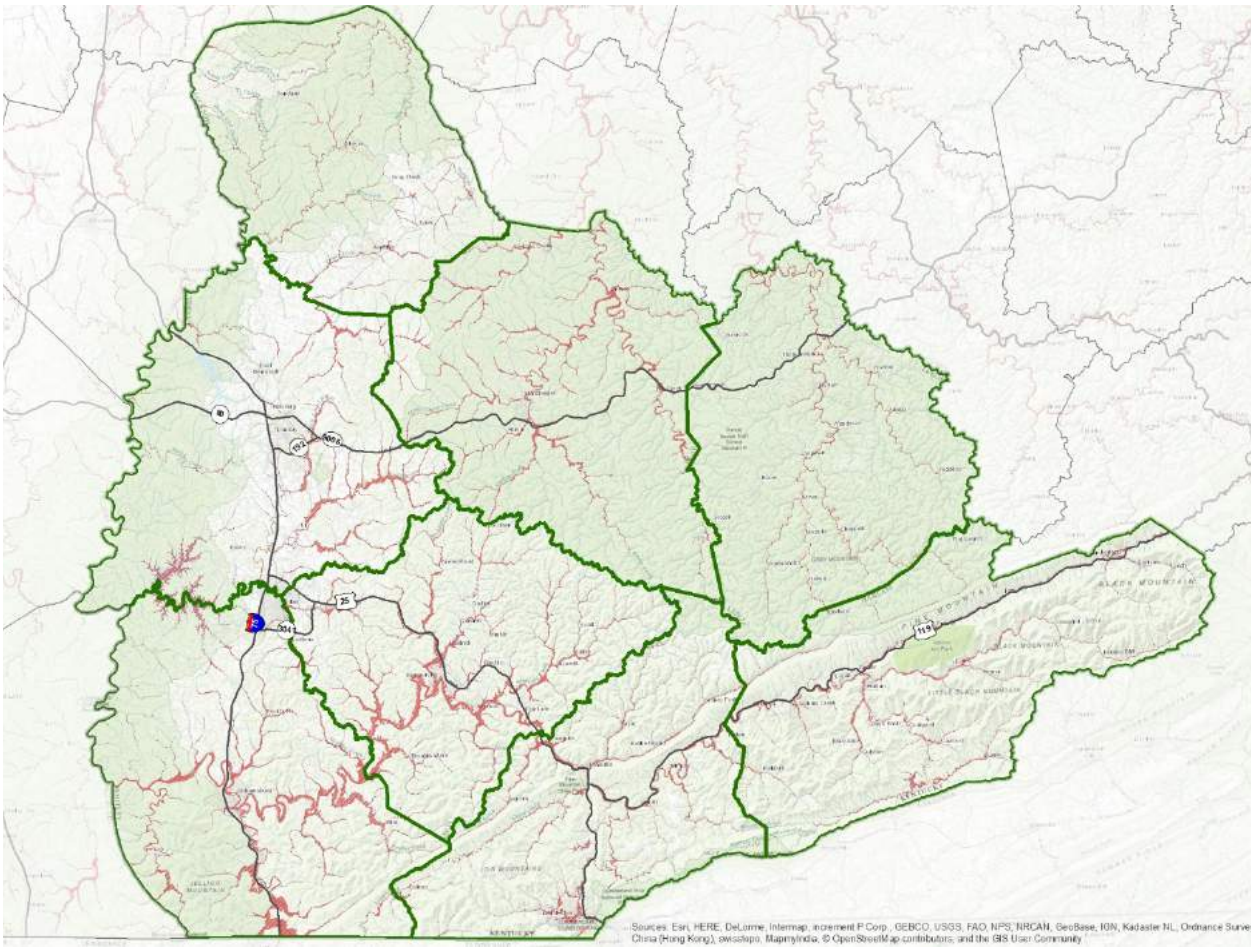

Figure 11-3. KYTC District 11; location of 100-year floodplain

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

11.2.3. Landslide

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

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

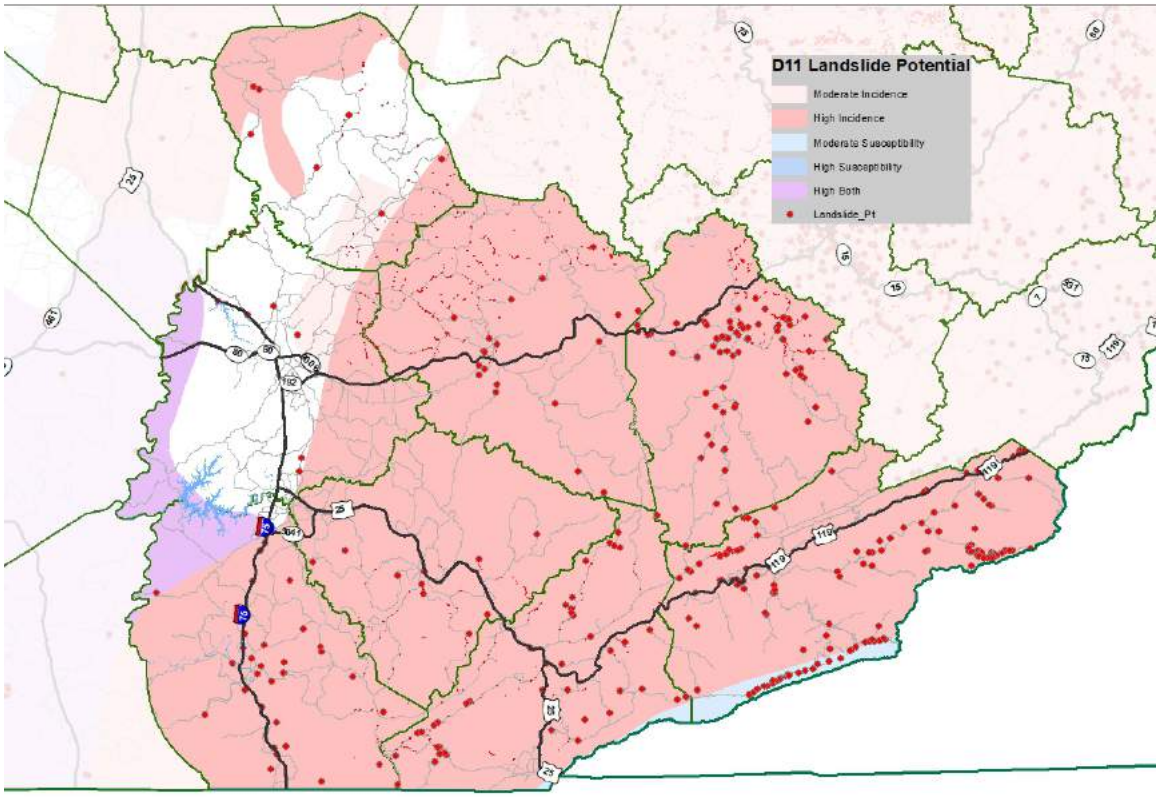

Figure 11-4. Landslide incidence and susceptibility in KYTC District 11

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

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

11.2.4. Karst

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

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

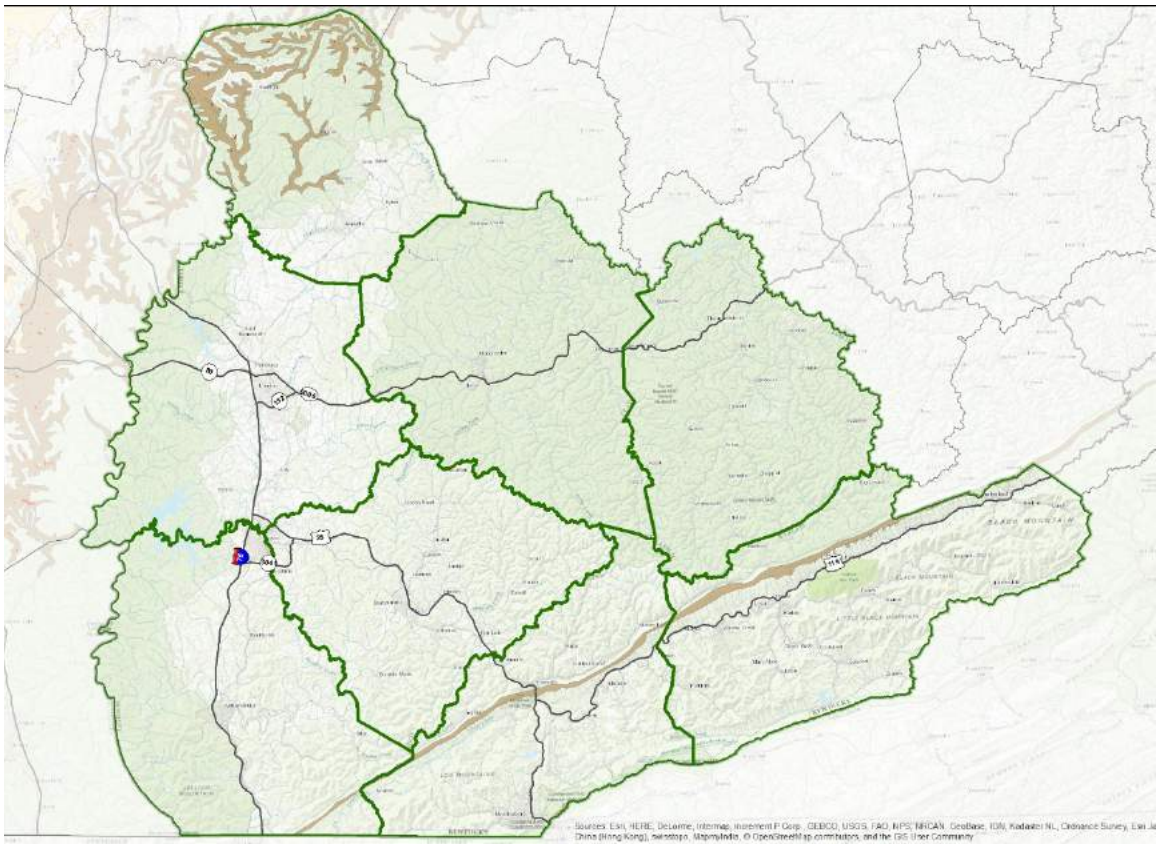

Figure 11-5. Karst potential and sinkholes in KYTC District 11

11.2.5. Other Meteorological Hazards

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

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

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

11.3. Workshop

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

11.3.1. Polling Results

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

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

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

11.3.2. Map Exercise

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

Table 11-3. District 11 NHS segments and flood

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

11.3.3. Workshop discussion

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

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

11.3.4. Roadways outside of the NHS that flood

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

11.3.5. Maintenance facilities flooding

No maintenance facilities in District 11 were reported to flood.

11.3.6. Consensus workshop

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

Table 11-4. Results of District 11 consensus workshop

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

11.4. Results

11.4.1. Identification of most at vulnerable assets

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

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

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

11.4.2. Worst case scenario

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

12. KYTC District 12

12.1. District Overview

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

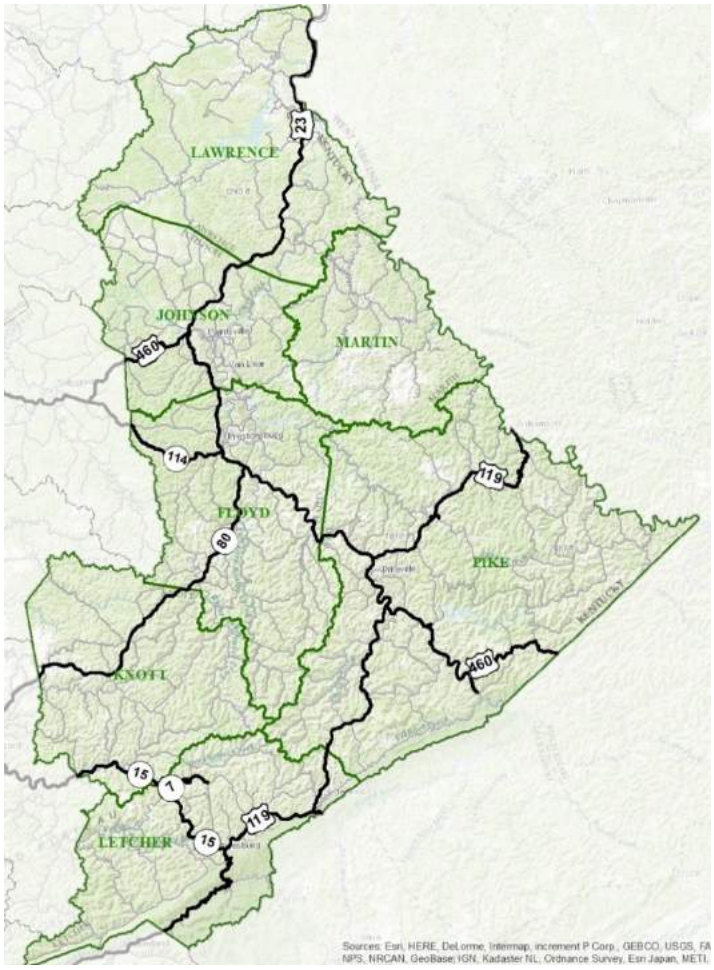

Figure 12-1. KYTC District 12 NHS

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

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

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

12.2. Hazards

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

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

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

12.2.1. Earthquake

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

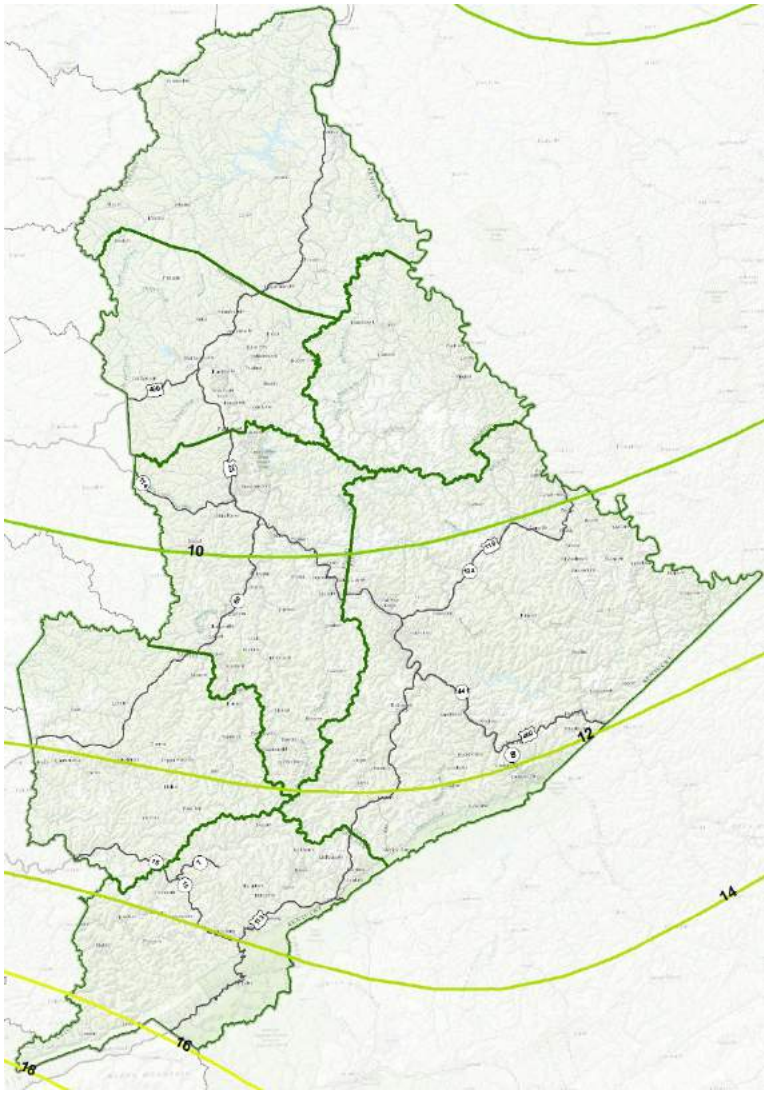

Figure 12-2. PGA Zones in KYTC District 12

12.2.2. Flood

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

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

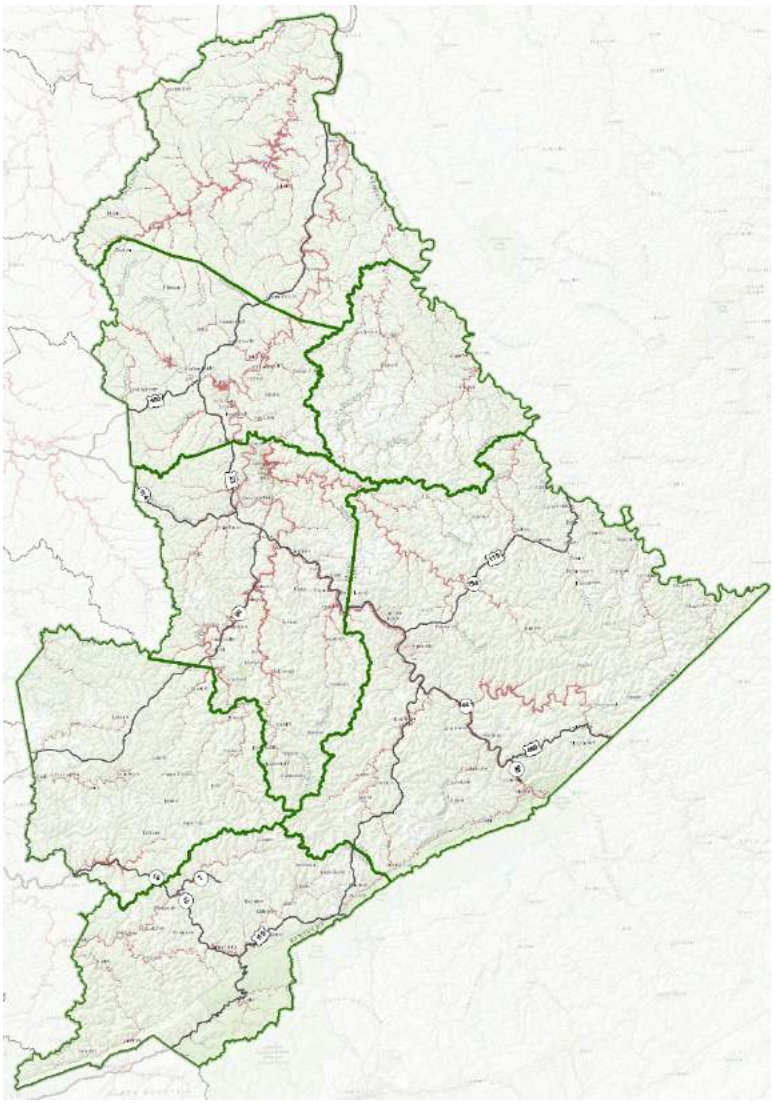

Figure 12-3. KYTC District 12 100-year floodplain

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

12.2.3. Landslide

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

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

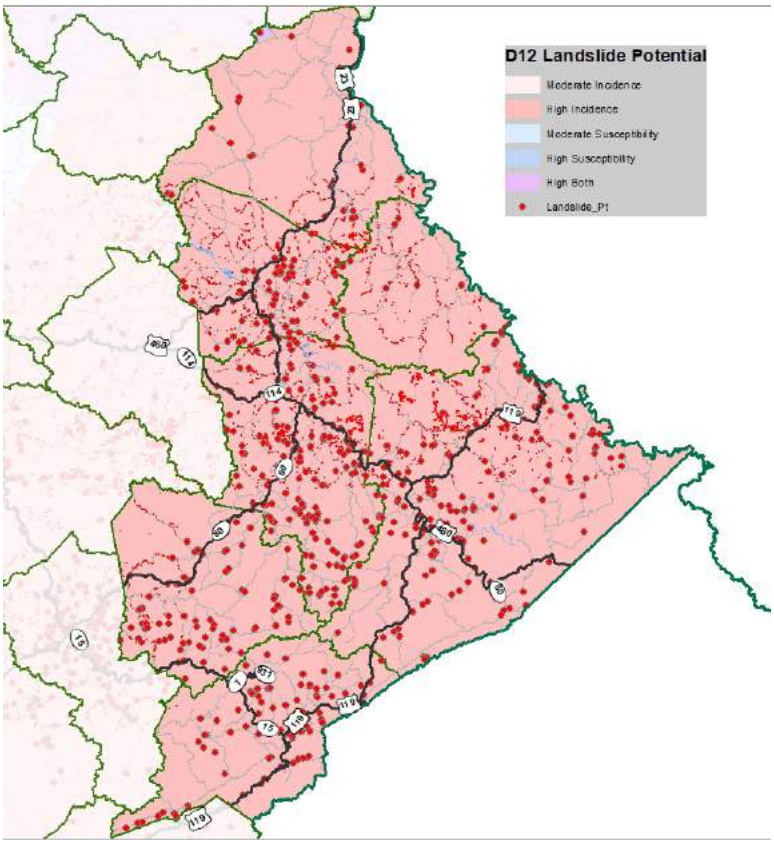

Figure 12-4. Landslide incidence and susceptibility in KYTC District 12

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

- Landslide US 23 near Lomansville; Lawrence County
- Landslide Correction on US 23 MP 27.1 NB; Lawrence County
- Landslide US 23 MP 7.3; Lawrence County
- Landslide US 23 at intersection with KY 1100; Johnson County
- Landslide KY 2555 MP 0.044; Floyd County
- Rockfall KY 114 MP 2.6; Floyd County
- Landslide KY 23 near Allen; Floyd County
- Landslide on Pennington Ln of US 23; Floyd County
- Landslide US 23 MP 8 NB, road closed; Floyd County
- Rockfall US 23 MP 7; Floyd County
- Rockfall KY 80 MP 8.8, Floyd County
- Rockfall KY 80 between MP 9 and MP 10; Floyd County
- Landslide KY 80 MP 1.5; Knott County

- Landslide KY 80 MP 8.5; Hindman County
- Mudslide KY 15 MP 6.2; Knott County
- Rockfall US 23 MP 27.1 NB; Pike County
- Landslide US 119 multiple location between MP 23.5 and MP 31; Pike County
- Landslide US 460; Pike County
- Rockfall US 460 MP 14; Pike County
- Landslide KY 1441; Pike County
- Landslide KY 80; Pike County

12.2.4. Karst

Sinkholes are not a significant hazard in District 12. The majority of the district is not located in karst-prone areas. Only a thin band along Pine Mountain in Letcher County and Pike County has the potential for karst formation. District 12 has 5 miles of NHS highway that intersect this area of high karst potential, this being sections of US 119 and US 23 in Letcher County.

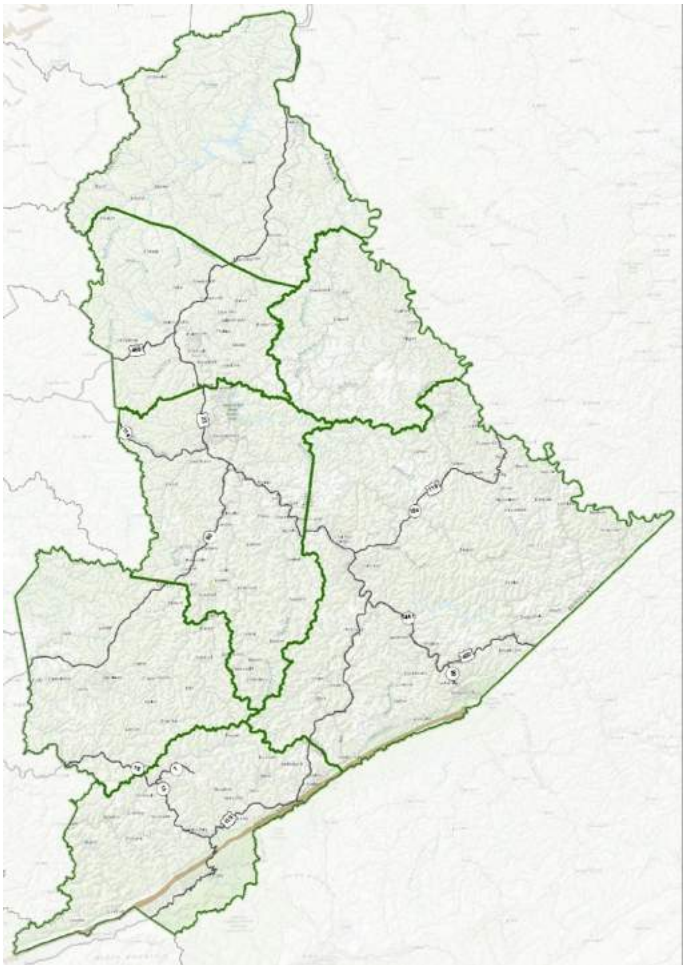

Figure 12-5. Karst potential and sinkholes in KYTC District 12

12.2.5. Other Meteorological Hazards

- Snow/Ice: District 12 annual snowfall averages vary considerably from north to south. Northern areas of the district, including Johnson County and Lawrence County, average

12” to 14” of snowfall annually, which is above the state average. Annual snowfall increases moving southward through the district, with Letcher County and southern Pike County averaging greater than 20” annual snowfall. These totals along the Virginia border in Letcher County and Pike County are highest in the state.

- Freeze/thaw: District 12 counties average between 85 and 104 annual freeze/thaw days. Given the topography of the region, the actual number of freeze/thaw days in a county likely varies depending on the elevation temperature gauges are located.
- Extreme heat: District 12 counties average 1-2 days annually where the temperature exceeds 95 degrees Fahrenheit, compared to the statewide average of 4 such days annually. These are among the lowest in the state.
- Drought/wildfire: Wildfires are more common in District 12 compared to the rest of the state. For the years 2002 to 2016, the district averaged nearly 20 documented wildfires each year. While most of these were small and their impacts minimal, several were significant. In 2016, a wildfire on Pine Mountain in Letcher County along the Virginia border burned over two thousand acres. In 2012, a wildfire on Pine Mountain along the Virginia border at Pike County burned 824 acres. Both of these larger wildfires occurred in wooded areas with minimal population. NHS assets were not impacted.
- Tornado: Compared to other districts in the state, District 12 has above average vulnerability to tornadoes. Tornado vulnerability is fairly even throughout the district, as all ten counties have experienced at least one F3 or above tornado since 1950. From 1950 to 2015, District 12 had 64 tornadoes overall, and 15 of intensity F3 and above tornadoes.

12.3. Workshop

The research team conducted a facilitated workshop in District 12 in August 2017. Eleven KYTC personnel attended the workshop. During the three hour workshop, data was collected from participants through a series of facilitated events, including; a) two keypad exercises where participants were asked to score the criticality of the roadway and the potential impacts of an extreme weather and/or natural hazard event, b) a mapping exercise with a focused conversation to contextualize flooding events in the District, and c) a consensus workshop where participants identified and discussed challenges to performing transportation system maintenance.

12.3.1. Polling Results

For workshop mapping exercises, the NHS was divided into 20 functional roadway segments based upon road designation and county location. Workshop participants were provided with keypads and asked to evaluate each of the NHS segments for criticality and potential impacts from extreme weather and natural hazards. An overall vulnerability score for each segment was computed by multiplying together the criticality and impacts ratings. The vulnerability score, then, provided a metric for identifying the most important highway segments that could potentially suffer the most damage from natural hazards. Table 12-2 illustrates the results of the workshop keypad assessments. The final column ranks each segment by the vulnerability score.

Table 12-2. District 12 workshop polling results showing criticality, impacts, and vulnerability

Segment ID	Segment Description	Criticality	Impacts	Vulnerability	Rank
1	US 23: Lawrence County	8.2	6.6	54.0	11
2	US 23: Johnson County	8.4	6.4	53.5	12
3	US 460: Johnson County	7.1	6.2	43.8	15
4	KY 114: Floyd County	8.3	7.5	62.4	8
5	US 23: Floyd County	8.7	8.2	71.4	2
6	From US 23 South to Ivel Coal Tipple Entrance	3.8	2.2	8.3	20
7	KY 80: Floyd County	7.7	8.0	61.8	9.5
8	KY 80: Knott County	8.0	7.7	61.8	9.5
9	KY 15: Knott County	7.4	7.2	52.9	13
10	KY 7/KY 931: Golden Oak coal tipple connector	5.5	3.2	17.4	16
11	KY 15: Letcher County	7.7	6.7	52.0	14
12	US 119: Letcher County	8.5	8.2	69.9	4
13	US 23: Letcher County	8.5	8.1	69.1	5
14	US 23: Pike County from CR 1267Y to Letcher County line	8.6	8.2	70.7	3
15	US 23: Pike County from CR 1267Y to Floyd County line	8.8	8.5	75.4	1
16	US 119: Pike County	8.5	8.0	67.6	6
17	KY 194: Bevins Branch Prep Plant connector	4.5	2.9	13.0	17
18	US 460: Pike County	7.9	8.3	65.4	7
19	KY 1441/KY 1789: CCI-Energy Slones Branch Terminal connector	3.8	2.4	9.0	19
20	From US 460 to CR 1613A (Cedar Hill Road)	3.3	3.0	9.8	18

12.3.2. Map Exercise

Workshop participants were asked to review and mark-up eight detailed maps of the NHS in District 12. The maps included NHS roadway segments and the associated bridges, culverts, and other structures; other state highways; streams, rivers, and other bodies of water; and the 100-year floodplain. Participants were asked to mark the maps and provide as much detail as possible for areas along the NHS that have A) flooded in the past, B) have been close to flooding in the past, and C) are likely to flood during an extreme weather event. Table 12-3 displays the results of this exercise.

Table 12-3. District 12 NHS segments and flood

District	County	MP	Route	Hazard	Intersecting feature
12	Lawrence	6.18	US-23	Has nearly flooded	confluence R Gorges/Gorges Creek
12	Johnson	0	US-23	Has flooded	by junction with KY-1750
12	Floyd	5.65	US-23	Has flooded	Levisa Fork/Tom's Creek
12	Floyd	0	US-23	Has flooded	Border with Johnson MP0
12	Floyd	6.75	US-23	Has flooded	Levisa Fork near Ivy Creek
12	Pike	26.9	US-23	Has nearly flooded	Tollage Creek/Levisa Fork

12.3.3. Workshop Discussion

Similar to the other eastern Kentucky districts, District 12 is vulnerable to flash flooding and landslides. Because of the topography, roads are generally located in valleys, which is where impacts from flash flooding can be the greatest. Because of this, district personnel stated that pretty much all roads in the district are vulnerable if the precipitation is heavy enough.

In 2015, Flat Gap in Johnson County experienced a devastating flash flood after 5 to 6 inches of rain fell over the area. Four people were killed in the flood and hundreds of homes were damaged or destroyed. District personnel described the flood as a wall of water from hillside to hillside that moved down KY 72. Damage to the transportation system included a bridge on KY 1559 being critically damaged and a bridge on KY 689 being damaged by a house hitting it. A similar type of flash flood hit Pike County in 2010, resulting in two fatalities. During this event, three to seven inches of rain fell over parts of Pike County, with Raccoon Creek being hit the hardest. Multiple homes and vehicles were damaged in the flood.

Flash flooding can result in communities being cutoff as road are flooded. District personnel recalled two occasions where Levisa Fork flooded over US 23, resulting in the town of Ivel being cutoff – sometimes for several days.

12.3.4. Roadways outside of the NHS that flood

District personnel identified multiple roads off the NHS that routinely flood. These include:

- Floyd County – KY 194 at Johns Creek
- KY 1428 east of Prestonsburg
- KY 1210 and KY 122 south of Martin

- KY 122 near Melvin
- Johnson County — KY 581 and KY 80 at the railroad overpass
- US 23 at KY 1750
- Letcher County — KY 313 and KY 343 both flood and have erosion problems
- Martin County — KY 292 near Warfield
- KY 40 south of Inez
- Pike County — KY 1460 south of Pikeville
- KY 319 just south of US 119
- KY 1056 near Tug Fork
- KY 1499 near KY 194
- KY 3227 at US 23

12.3.5. Maintenance facilities flooding

The KYTC maintenance facilities in Johnson County were affected by the 2015 floods.

12.3.6. Consensus workshop

After the discussion of flooding in District 12, participants engaged in a consensus workshop where the following question was posed "What are the Biggest Challenges to Conducting Maintenance in District 12?" Participants were asked to individually brainstorm, then discuss their brainstorm ideas with a partner, and share their ideas with the entire group. Table 12-4 shows the final results from the consensus workshop.

Table 12-4. Results of District 12 consensus workshop

Identified Challenges to Conducting Maintenance Operations in District 12						
Public Response vs. General Maintenance	**Cross Training and Higher Quality Personnel**	**Challenging Locations**	**Construction vs. Maintenance**	**Funding**	**Utility Demands**	**Who has Ownership/Control of Equipment**
Demands of Elected Officials	Personnel -training -absenteeism	Terrain	Putting out fires	No Funding	Dealing with 811	Equipment -Type -Breakdowns
Public Expectations	Program for quick Bridge Repair	Extreme Weather	More focus on Maintenance Management	Need More Flexibility to Determine where Money goes	Utilities	Cannot get parts for Equipment
More Timely Response	Need Better Ownership by Supervisors		Being more Efficient	More Funding	811	Buying wrong types of Equipment
			Illegal Entrances	Money	System is inefficient	Equipment
			Need Routine Maintenance	Funding	Utility lines are too shallow	Need Better Access
				Not Enough Funding	Too many demands	Need a Faster Parts Process

12.4. Results

12.4.1. Identification of most vulnerable assets

Table 12-5 lists District 12 NHS assets with a vulnerability score of 3.5 or greater for any of the four major hazards in this analysis (a full list of District 12 NHS assets and vulnerability scores is in Appendix 2). Landslide is the one hazard that causes the greatest vulnerability in District 12, with US-23 in Floyd County having the highest vulnerability score. Nearly all District 12 NHS segments have high vulnerability to landslide, with a few notable exceptions, including US-460 in Johnson County, KY-15 in Letcher County, and US-23 in Letcher County.

Table 12-5. District 12 NHS assets with vulnerability score 3.5 or greater

District	County	Route	Vulnerability Score	Hazard
12	Knott	KY 15	**3.53**	Landslide
12	Johnson	US 23	**3.60**	Landslide
12	Knott	KY 80	**3.60**	Landslide
12	Lawrence	US 23	**3.60**	Landslide
12	Letcher	US 119	**3.62**	Landslide
12	Pike	US 23	**3.62**	Landslide
12	Pike	US 460	**3.62**	Landslide
12	Floyd	KY 114	**3.68**	Landslide
12	Floyd	KY 80	**3.68**	Landslide
12	Pike	US 119	**3.77**	Landslide
12	Pike	US 23	**3.78**	Landslide
12	Floyd	US 23	**3.83**	Landslide

12.4.2. Worst case scenario

District 12 does not have any interstate or parkway lane miles. Several highways on the NHS serve as critical routes in the district, particularly US 23 and US 119. Any flash flooding that knocked out segments of these roads would constitute the worst case scenario. Because the area is so vulnerable to flash flooding, district personnel believed such flooding is a matter of when, not if.

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14. Appendices

14.1. Appendix 1: VAST Data Inputs

Listing and description of the 22 datasets used as input indicators for the VAST analysis. Data for each indicator were reclassified from 1 to 4. The thresholds used for each reclassification are demonstrated in the table below.

Indicator Type	Hazard Type	Description	Measure/Units	1	2	3	4	Source
Exposure	Earthquake	Peak Ground Acceleration	Max PGA zone wherein asset lies	6 to 17	18 to 39	40 to 79	80 to 120	USGS[25]
Exposure	Flood	Historical Precipitation	Historical average annual # of days where precipitation >3"	0 to .11	.11 to .22	.22 to .33	.33 to .51	Data provided by Midwest Regional Climate Center
Exposure	Flood	Projected Precipitation	Future projected average annual # of days where precipitation >1"		7	9	11	Kunkel et al[26]
Exposure	Flood	KGS Flood Hazard layer	Segments intersecting this layer	No			Yes	KGS[27]
Exposure	Flood	Location via 100-yr floodplain	Percent of centerline miles located in floodplain	0	0 to 1	2 to 5	>5	KTC GIS analysis
Exposure	Landslide	USGS Landslide susceptibility	Percent of centerline miles located in high landslide zone	0	0 to 10	10 to 20	>20	USGS[28]
Exposure	Landslide	Max slope	Maximum slope within 200' of centerline	0 to 50	50 to 100	100 to 150	>150	KTC GIS analysis
Exposure	Landslide	Mean slope	Mean slope along NHS segment within 200' of centerline	0 to 5	5 to 10	10 to 15	>15	KTC GIS analysis

[25] USGS, "PGA 2% in 50 Yrs."
[26] Kunkel et al., "Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 2. Climate of the Southeast U.S."
[27] Carey, Hounshell, and Kiefer, "Geologic Hazards in Kentucky."
[28] Godt, "Digital Compilation of Landslide Overview Map of The Conterminous United States."

Indicator Type	Hazard Type	Description	Measure/Units	1	2	3	4	Source
Exposure	Landslide	KGS Slope Stability/Landslide layer	Segments intersecting this layer	No			Yes	KGS[29]
Exposure	Landslide	KGS Landslide Inventory	Landslides within 500' of NHS per centerline mile	0	.1 to .5	.51 to 1.5	>1.5	KGS[30]
Exposure	Sinkhole	KGS Karst Potential	Percent of centerline miles located in high karst zone	0	1 to 33	34 to 66	>66	KGS[31]
Exposure	Sinkhole	KGS Karst Hazard layer	Segments intersecting this layer	No			Yes	KGS[32]
Exposure	Sinkhole	KGS Sinkhole database	Acres of sinkholes per centerline miles	0	.1 to 5	5.1 to 10	>10	KGS[33]
Sensitivity	Flood	Workshop mapping results	NHS segments identified in workshops as having flooded	No			Yes	KYTC district workshops
Sensitivity	Flood	FEMA flood event	NHS segments that experienced FHWA/FEMA response flood events	No			Yes	FHWA/KYTC/FEMA. Data provided by KYTC
Sensitivity	Landslide	Workshop landslide results	NHS segments identified in workshops as having landslides	No			Yes	KYTC district workshops
Sensitivity	Landslide	FEMA slide event	NHS segments that experience FHWA/FEMA response landslide events	No			Yes	FHWA/KYTC/FEMA. Data provided by KYTC
Sensitivity	Sinkhole	Workshop sinkhole results	NHS segments identified in workshops as having sinkholes	No			Yes	KYTC district workshops

[29] Carey, Hounshell, and Kiefer, "Geologic Hazards in Kentucky."
[30] KGS, "Landslide Hazards in Kentucky."
[31] Paylor and Currens, "Karst Occurrence in Kentucky."
[32] Carey, Hounshell, and Kiefer, "Geologic Hazards in Kentucky."
[33] Paylor et al., "GIS Sinkhole Database."

Indicator Type	Hazard Type	Description	Measure/Units	1	2	3	4	Source
Adaptive Capacity	ALL	AADT	Max average annual daily traffic on NHS segment	0 to 8,000	8,001 to 16,000	16,001 to 24,000	>24,000	KYTC Highway Information System (HIS) Database[34]
Adaptive Capacity	ALL	Criticality Rating	Workshop keypad criticality rating of NHS segment	1 to 2.25	2.26 to 4.5	4.56 to 6.75	>6.75	KYTC district workshops
Adaptive Capacity	ALL	Functional Class	Functional classification of NHS segment	7	5,6	3,4	1,2	KYTC HIS
Adaptive Capacity	ALL	Impacts Rating	Workshop keypad impacts rating of NHS segment	1 to 2.25	2.26 to 4.5	4.56 to 6.75	>6.75	KYTC district workshops

[34] KYTC, "Highway Information System GIS Extracts."

14.2. Appendix 2: VAST Results for All NHS Segments

Vulnerability scores on flood, landslide, sinkhole, and earthquake for all KYTC NHS highway segments. Vulnerability scales from 1 to 4, where 4 indicates highest vulnerability.

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
1	1	Ballard	US 51	16.86	3.83	1.89	3.43	2.36
1	2	Ballard	US 60	4.58	3.50	1.67	3.54	2.07
1	3	McCracken	US 60	10.70	3.67	1.78	2.57	1.84
1	4	McCracken	I-24	2.96	3.50	2.00	2.71	2.07
1	5	McCracken	US 45	10.80	3.00	1.67	2.38	2.00
1	6	McCracken	US 60 / US 45X / US 60X	10.92	3.00	1.67	3.37	3.00
1	7	McCracken	US 60 / US 68 / US 62	9.63	3.00	1.67	3.46	2.73
1	8	McCracken	I-24	14.33	3.38	1.92	3.29	3.32
1	9	Graves	US 45	13.37	3.00	1.67	2.63	1.87
1	10	Graves	JC 9003	9.80	3.13	1.75	3.38	2.02
1	11	Fulton/Hickman	JC 9003 / US 51 / CR 1013	8.94	3.13	1.75	3.54	1.88
1	12	Graves	JC 9003	16.42	3.00	1.67	3.54	2.00
1	13	Graves	KY 121 / KY 80	12.89	2.75	1.50	3.13	1.70
1	14	Marshall	I-24	12.03	3.38	1.92	2.88	2.18
1	15	Marshall	JC 9003	16.95	3.25	1.83	2.71	3.23
1	16	Marshall	KY 348 / US 641S / US 641	14.17	3.00	1.67	2.54	2.00
1	17	Calloway	US 641	6.17	2.75	1.50	2.46	1.70
1	18	Calloway	US 641	11.26	3.00	1.67	2.54	1.87
1	19	Calloway/Marshall	KY 80 / US 68	25.54	2.75	1.50	2.46	1.83
1	20	Livingston	I-24	4.50	3.38	1.92	2.88	2.25
1	21	Lyon	I-69	5.64	2.63	2.53	2.21	2.08
1	22	Lyon	I-24	20.97	3.38	2.70	2.71	3.18
1	23	Trigg	US 68	28.12	2.38	2.58	2.54	1.92
1	24	Trigg	I-24	12.48	2.88	3.92	2.54	1.92

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
2	1	Henderson	US 41	10.19	3.00	2.00	3.87	3.33
2	2	Henderson	US 60 / US 41A / KY 351	7.20	2.63	1.75	3.54	1.95
2	3	Henderson	KY 425	4.74	2.38	1.58	3.04	1.78
2	4	Henderson	AU 9005	15.87	2.75	1.83	3.54	3.30
2	5	Henderson	I-69	10.95	2.63	1.75	3.54	2.02
2	6	Daviess	US 231	3.56	2.25	1.50	3.04	1.50
2	7	Daviess	US 60	17.55	2.88	1.92	3.46	2.18
2	8	Daviess	CS 1060 / KY 331	2.44	2.25	1.50	2.29	1.77
2	9	Daviess	KY 2262	1.51	2.63	1.75	2.38	1.75
2	10	Daviess	AU 9005	7.60	2.75	1.83	3.71	3.17
2	11	Daviess	KY 81 / KY 54	5.16	2.38	1.58	3.21	1.78
2	12	Daviess	KY 2155	3.73	2.38	1.58	3.21	1.78
2	13	Daviess	KY 2831	2.56	2.38	1.58	3.21	1.58
2	14	Daviess	WN 9007	10.75	2.63	1.75	3.63	2.02
2	15	Webster	I-69	10.31	2.75	1.83	2.63	2.23
2	16	Ohio	WN 9007	24.35	2.63	2.08	2.46	3.22
2	17	Ohio	WK 9001	21.94	2.25	1.83	2.63	3.37
2	18	Hopkins	I-69	15.26	2.75	1.83	3.71	2.17
2	19	Muhlenberg/Hopkins	WK 9001 / I-69	27.37	2.75	1.83	2.63	3.23
2	20	Hopkins	I-69	21.79	2.75	1.83	2.63	3.30
2	21	Caldwell	I-69	16.18	2.75	3.72	3.62	3.30
2	22	Christian/Hopkins	EB 9004	22.60	2.88	2.47	2.79	2.25
2	23	Christian	US 41 / US 68	21.10	2.50	2.56	3.37	1.67
2	24	Christian	US 68B	11.05	2.50	3.56	3.29	1.67
2	25	Christian	I-24	23.48	3.00	4.00	3.54	3.13
2	26	Christian	US 41A	16.00	2.75	3.83	3.46	1.83
2	27	Christian	EB 9004	11.79	2.88	3.92	3.62	2.05
2	28	Caldwell	I-24	2.56	2.88	2.70	2.46	1.92

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
3	1	Butler	WK 9001 / WN 9007	17.82	2.13	2.08	2.63	3.22
3	2	Barren/Edmonson	I-65	11.07	2.50	4.00	2.46	2.13
3	3	Barren	LN 9008	8.72	2.25	2.61	2.38	2.17
3	4	Barren	LN 9008	13.65	2.25	2.50	2.38	3.23
3	5	Metcalfe	LN 9008	13.81	2.13	2.53	2.29	3.28
3	6	Warren	WN 9007	10.72	2.25	2.50	2.54	3.10
3	7	Warren	US 68 / US 31W / KY 446	10.75	2.38	2.81	2.88	1.98
3	8	Warren	I-65	14.91	2.50	4.00	2.46	2.13
3	9	Warren	I-65	14.33	2.50	4.00	2.79	2.07
3	10	Warren	US 68	8.22	2.13	3.75	2.38	1.75
3	11	Warren	WN 9007	9.53	2.38	3.92	2.46	1.92
3	12	Warren	US 231	13.92	2.13	3.75	3.54	1.88
3	13	Logan	US 68	15.09	1.88	2.58	2.54	1.58
3	14	Logan	US 68	14.09	1.88	2.36	2.29	1.58
3	15	Logan	US 431 / US 79	11.70	1.75	2.28	3.21	1.50
3	16	Todd	US 68	14.36	2.25	2.28	2.13	1.50
3	17	Todd	US 79	10.59	2.25	3.50	2.21	1.50
3	18	Simpson	I-65	13.76	2.50	4.00	2.63	2.13
3	19	Allen	US 231	8.56	1.88	2.25	2.13	1.85
3	20	Allen	US 31E	8.60	1.88	2.03	3.29	1.98
3	21	Warren	KY 880 / KY 234	3.39	2.13	2.75	2.21	1.75
4	1	Grayson	WK 9001	31.30	2.13	2.19	2.63	3.28
4	2	Hardin	US 31W	4.12	2.00	2.22	3.63	1.80
4	3	Meade	US 31W	3.53	2.00	2.67	2.04	2.00
4	4	Hardin	US 31W	8.83	2.00	3.67	2.13	1.67
4	5	Hardin	US 31W	5.61	2.00	2.67	2.29	1.67
4	6	Hardin	US 31WB	3.53	1.88	3.36	2.21	1.65
4	7	Hardin	KY 313	9.49	1.63	1.97	3.38	3.02

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
4	8	Hardin	I-65	12.21	2.50	3.67	2.96	2.53
4	9	Hardin	WK 9001	17.37	2.25	3.72	2.63	1.97
4	10	Hardin	BG 9002	8.82	2.13	2.31	2.71	2.22
4	11	Hardin	I-65	12.37	2.50	3.89	3.87	2.07
4	12	Larue	I-65	4.05	2.50	4.00	2.37	2.13
4	13	Hart	I-65	20.76	2.50	4.00	2.88	2.40
4	14	Nelson	BG 9002	30.48	2.13	2.19	2.54	3.15
4	15	Washington	BG 9002	5.49	2.13	1.75	2.21	2.22
4	16	Washington	KY 555 / KY 55	19.28	1.75	1.83	2.04	1.90
4	17	Marion	KY 2154 / KY 55	6.06	1.75	1.94	2.13	1.77
4	18	Marion	US 68	9.35	1.75	1.83	3.38	1.83
4	19	Taylor	US 68	8.69	2.00	2.11	2.13	1.93
4	20	Taylor	KY 55	10.27	1.88	2.14	2.29	1.92
5	1	Jefferson	I-64	6.14	2.25	1.94	3.46	2.17
5	2	Jefferson	I-64	12.65	2.25	2.28	3.29	2.17
5	3	Jefferson	I-64	5.17	2.13	2.19	2.13	2.08
5	4	Jefferson	I-65	0.00	1.75	1.50	3.04	1.57
5	5	Jefferson	I-65	1.51	2.13	1.75	3.29	1.88
5	6	Jefferson	I-65	6.42	2.13	1.97	3.29	1.95
5	7	Jefferson	I-65	6.23	2.25	1.94	2.54	3.10
5	8	Jefferson	I-71	11.25	2.25	2.28	2.54	2.23
5	9	Jefferson	I-264	12.66	2.13	1.86	3.46	2.02
5	10	Jefferson	I-264	10.24	2.25	3.28	2.21	2.03
5	11	Jefferson	KY 841	10.23	2.38	1.92	2.54	3.32
5	12	Jefferson	I-265	24.46	2.25	2.50	2.12	3.37
5	13	Jefferson	KY 841	4.15	2.00	2.11	2.21	1.93
5	14	Jefferson	US 31	1.12	1.75	1.50	3.04	1.50

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
5	15	Jefferson	CS 1124A / KY 1020 / CS 1036A / CS 1014B / CS 1009B / CS 1006F	1.09	1.88	1.58	3.38	1.58
5	16	Jefferson	CS 1011F / CS 1009A / CS 1004A / CS 1049F / CS 1046A	1.32	1.75	1.50	2.04	1.50
5	17	Jefferson	US 150T / US 150 / US 31W	26.72	2.13	1.75	3.54	2.02
5	18	Jefferson	CR 1020G / US 31E	14.28	2.00	2.00	2.38	1.87
5	19	Jefferson	US 42	9.95	2.00	2.11	3.37	2.00
5	20	Jefferson	CS 1021F / US 150	4.43	1.88	1.69	2.38	1.78
5	21	Jefferson	KY 2056 / KY 2051 / KY 1934 / CR 1012F / CR 1002F	15.65	2.25	1.83	2.63	1.90
5	22	Jefferson	KY 1865	5.02	2.00	1.67	2.29	1.87
5	23	Jefferson	CR 1001G	1.04	2.00	1.67	2.21	1.87
5	24	Jefferson	KY 1703 / CR 1016G / CR 1010G	1.13	2.13	2.08	2.29	1.95
5	25	Jefferson	KY 22 / KY 1747	18.06	2.00	2.11	2.38	1.87
5	26	Jefferson	KY 155	10.52	1.88	1.92	1.96	1.85
5	27	Jefferson	US 60	12.16	2.13	2.08	2.13	1.95
5	28	Jefferson	KY 1447	4.75	1.88	2.03	2.04	1.78
5	29	Jefferson	KY 913	4.35	2.00	1.89	1.96	1.93
5	30	Oldham	I-71	13.52	2.25	2.06	2.29	2.23
5	31	Henry/Trimble	I-71	14.02	2.13	2.08	2.21	3.28
5	32	Shelby	I-64	22.33	2.25	2.28	3.29	3.23
5	33	Franklin	I-64	13.14	2.38	2.58	2.54	3.45
5	34	Franklin	US 127	10.93	1.88	2.25	2.29	3.12
5	35	Franklin	US 421 / US 60	4.81	2.25	2.83	2.46	1.97
5	36	Franklin	KY 676	5.28	1.75	2.28	2.13	2.97
5	37	Bullitt	I-65	19.91	2.38	2.03	2.63	3.32
6	1	Carroll	I-71	14.64	2.38	2.36	3.62	3.52

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
6	2	Gallatin	I-71	16.43	2.38	2.25	2.46	3.52
6	3	Boone	I-71	7.83	2.38	2.25	2.29	3.45
6	4	Grant	I-75	23.04	2.38	2.25	2.87	3.45
6	5	Boone/Kenton	I-75	5.05	2.38	2.36	2.21	3.25
6	6	Boone/Kenton	I-75	12.09	2.38	2.25	3.46	3.32
6	7	Kenton	I-75	6.73	2.50	2.33	3.54	3.73
6	8	Kenton	I-75	1.57	2.50	2.00	3.54	3.53
6	9	Boone	I-275	6.85	2.38	2.25	2.21	3.72
6	10	Boone/Kenton	I-275	7.05	2.38	2.25	2.54	3.65
6	11	Kenton/Campbell	I-275	6.23	2.50	2.33	2.54	3.73
6	12	Campbell	I-275	4.53	2.50	2.33	3.54	3.80
6	13	Campbell	CS 1006 / I-471	4.83	2.50	2.33	3.54	3.80
6	14	Campbell	I-471 / KY 471	0.96	2.50	2.00	3.71	2.33
6	15	Boone	KY 237	8.98	2.13	2.08	2.38	2.15
6	16	Boone	US 42	1.47	2.13	2.08	2.04	2.08
6	17	Boone	KY 18	3.30	2.13	2.08	2.38	3.15
6	18	Boone	KY 212	0.83	2.13	1.75	2.29	2.22
6	19	Kenton/Campbell	KY 8	3.78	2.00	1.67	3.21	1.93
6	20	Kenton/Campbell	KY 1120	3.42	2.00	1.67	2.21	3.00
6	21	Kenton	KY 17	0.39	1.88	1.58	2.13	1.78
6	22	Kenton	KY 17	6.91	2.13	1.75	2.96	2.28
6	23	Campbell	US 27	0.55	1.88	1.58	2.04	1.78
6	24	Campbell	US 27	3.49	1.88	1.92	3.04	3.12
6	25	Kenton	KY 16	2.87	2.00	2.00	2.96	2.33
6	26	Campbell	US 27	3.05	2.25	2.17	2.04	2.43
6	27	Campbell	KY 9	17.88	2.25	2.17	2.29	3.63
6	28	Pendleton	KY 9	4.33	1.75	1.83	1.71	2.10
6	29	Bracken	KY 9	19.80	1.75	1.83	1.79	3.17

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
6	30	Robertson	US 68	1.34	1.63	1.86	1.63	1.88
7	1	Anderson	US 127 / US 127B	11.36	1.88	2.25	1.96	1.92
7	2	Anderson/Mercer	BG 9002	17.18	2.25	2.39	2.21	2.37
7	3	Mercer	US 127 / US 127B	18.09	1.88	2.36	2.04	1.85
7	4	Boyle	US 127 / US 127B	10.98	1.88	2.36	2.04	1.78
7	5	Boyle	US 150 / US 150B	4.33	1.75	1.94	1.88	2.83
7	6	Woodford/Scott/Fayette	I-64	15.38	2.38	2.81	2.29	2.05
7	7	Woodford	US 60	13.03	2.00	2.45	2.04	1.93
7	8	Woodford	BG 9002	9.21	2.25	2.61	2.21	1.97
7	9	Scott	KY 3487 / KY 620 / US 62	8.48	2.00	2.45	1.96	3.00
7	10	Scott/Fayette	KY 1973 / US 25	3.29	1.88	2.25	2.13	1.58
7	11	Scott	I-75	18.38	2.38	2.58	2.21	3.45
7	12	Scott/Fayette	I-75	7.44	2.50	2.78	3.37	2.07
7	13	Fayette	I-75	13.55	2.38	2.70	2.29	3.32
7	14	Fayette	I-75	6.19	2.50	2.78	2.29	2.33
7	15	Fayette	I-64	8.40	2.38	2.58	2.21	2.05
7	16	Fayette	KY 4	13.80	2.25	2.61	2.21	2.17
7	17	Fayette	KY 4	5.51	2.13	2.42	3.21	1.95
7	18	Fayette	KY 922	3.39	2.13	2.53	2.21	1.75
7	19	Fayette	KY 1681 / US 421	2.10	1.88	2.25	1.88	1.58
7	20	Fayette	US 60	8.67	2.13	2.53	2.13	1.88
7	21	Fayette	US 68	4.56	2.00	2.45	1.96	1.67
7	22	Fayette	CS 4745 / US 27 / CS 7087	11.83	2.13	2.53	3.21	1.75
7	23	Fayette	KY 1974	4.26	2.00	2.45	2.21	1.87
7	24	Fayette	KY 418 / US 25	10.44	2.13	2.53	2.04	1.95
7	25	Fayette	US 60	3.92	2.00	2.45	2.04	1.87
7	26	Fayette	US 27	5.20	2.00	2.45	2.13	1.67

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
7	27	Fayette	CS 4909 / CS 4907 / CS 3288 / CS 3286	2.45	1.75	2.17	1.79	1.50
7	28	Fayette	CS 3016 / CS 4524	15.79	2.13	2.53	2.13	2.02
7	29	Jessamine	US 27	9.98	2.25	2.61	2.21	1.90
7	30	Jessamine	US 27	5.38	2.00	2.67	1.96	2.93
7	31	Garrard	US 27	16.66	2.00	2.33	2.13	3.07
7	32	Bourbon	US 68	10.75	1.75	2.17	2.04	2.63
7	33	Bourbon	US 27	8.76	1.88	2.36	2.04	1.65
7	34	Clark	I-64	14.79	2.25	2.50	2.12	2.17
7	35	Clark/Madison	KY 627 / KY 1958	15.14	2.13	2.42	3.12	2.22
7	36	Clark	KY 9000	11.90	2.13	2.19	2.13	3.15
7	37	Madison	I-75	24.35	2.50	2.44	3.29	3.80
7	38	Madison	US 25 / KY 876	7.74	2.00	2.11	1.96	1.93
7	39	Madison	US 421 / US 25 / KY 2872	5.22	1.88	2.03	1.79	1.78
7	40	Montgomery	I-64	11.43	2.38	2.25	2.29	3.52
8	1	Lincoln	US 127	10.66	2.00	2.11	2.13	2.07
8	2	Lincoln	US 150	5.47	1.88	1.92	3.04	1.92
8	3	Lincoln	US 27	21.91	2.13	2.31	3.21	3.22
8	4	Rockcastle	I-75	22.60	2.50	2.56	3.71	3.87
8	5	Rockcastle	US 25 / KY 461	10.21	2.00	2.45	2.13	2.27
8	6	Casey	US 127	23.92	2.13	2.08	3.63	3.28
8	7	Adair	KY 55X / KY 55	12.03	1.75	2.28	1.96	1.83
8	8	Adair	LN 9008	21.62	2.00	3.33	2.04	2.07
8	9	Russell	US 127	26.24	2.13	2.31	2.46	3.35
8	10	Russell	LN 9008	14.32	1.88	2.03	2.04	3.18
8	11	Pulaski	LN 9008	16.28	2.00	2.22	2.13	3.27
8	12	Pulaski	US 27	7.55	1.88	2.14	2.21	3.12
8	13	Pulaski	US 27	23.28	2.25	3.72	3.54	3.57

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
8	14	Pulaski	KY 80	20.80	2.13	2.53	2.54	3.42
8	15	Pulaski	KY 461	8.49	1.88	2.36	2.04	2.18
8	16	Pulaski	KY 914	13.33	1.88	3.58	3.04	1.92
8	17	Clinton	US 127	21.57	1.75	2.50	2.04	1.97
8	18	McCreary	US 27	22.28	1.88	1.58	2.29	2.32
9	1	Nicholas	US 68	12.13	1.63	2.08	1.88	1.82
9	2	Fleming	US 68	5.41	1.63	1.75	1.71	2.82
9	3	Mason	US 68	14.32	1.75	1.94	1.79	1.77
9	4	Mason	US 68	4.20	2.00	2.00	2.21	3.33
9	5	Mason	KY 9	19.56	2.00	2.11	1.96	3.07
9	6	Lewis	KY 9	31.02	1.75	1.61	3.04	3.03
9	7	Lewis	KY 10	12.97	1.75	1.50	2.62	3.10
9	8	Greenup	KY 10	11.60	1.63	1.42	1.88	1.88
9	9	Greenup	KY 10	1.21	1.88	1.58	2.21	1.65
9	10	Greenup	KY 8S / KY 8	1.66	1.88	1.58	1.96	3.05
9	11	Greenup	US 23	12.92	2.00	1.67	3.12	3.07
9	12	Greenup	US 23	15.92	2.25	1.83	3.37	3.70
9	13	Bath	I-64	13.32	2.25	1.83	3.12	3.37
9	14	Rowan	I-64	19.71	2.25	2.28	3.46	3.63
9	15	Carter	I-64	32.15	2.38	2.47	2.54	3.72
9	16	Carter	KY 9 / KY 1	18.76	1.63	1.53	2.04	2.08
9	17	Boyd	I-64	10.03	2.50	2.00	2.46	3.87
9	18	Boyd	I-64	0.57	2.38	1.92	2.29	2.45
9	19	Boyd	US 60 / KY 180	10.79	2.13	1.75	3.37	2.35
9	20	Boyd	US 60 / US 23S / CS 2551	1.11	2.13	1.75	2.29	3.28
9	21	Boyd	US 23 / US 23X	21.21	2.25	1.83	2.38	2.63
9	22	Boyd	KY 757	2.27	1.25	1.17	1.54	2.70
10	1	Powell	KY 9000	24.06	2.13	1.86	3.46	2.55

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
10	2	Wolfe	KY 9000	6.86	2.00	1.67	1.96	3.53
10	3	Wolfe	KY 9009 / KY 9000	14.80	2.00	1.67	3.21	3.67
10	4	Wolfe	KY 15S / KY 15	10.57	1.88	1.58	2.79	2.52
10	5	Morgan	KY 9009	5.39	2.00	1.67	3.21	2.60
10	6	Magoffin	KY 9009	12.56	1.88	1.58	3.04	3.58
10	7	Magoffin	US 460	7.85	2.00	1.67	2.04	3.60
10	8	Magoffin	KY 114	5.02	1.88	1.58	1.96	3.58
10	9	Breathitt	KY 15	25.62	2.00	1.67	3.21	3.67
10	10	Perry	KY 15	8.66	2.00	1.67	2.21	3.67
10	11	Perry	KY 15	16.57	2.25	1.83	2.46	2.83
10	12	Perry	HR 9006	8.09	2.13	1.75	2.29	3.75
10	13	Perry	KY 80	7.94	2.00	1.67	2.13	3.53
11	1	Laurel	I-75	22.85	2.50	3.44	2.63	3.67
11	2	Laurel	KY 80	11.26	2.13	2.19	2.29	2.22
11	3	Laurel	HR 9006	10.60	2.00	1.67	2.29	2.33
11	4	Laurel	KY 192	3.81	2.13	1.75	2.38	2.02
11	5	Clay	HR 9006	25.35	2.00	1.67	2.38	2.60
11	6	Leslie	HR 9006	15.08	1.88	1.58	2.29	2.45
11	7	Whitley	I-75	27.95	3.00	2.00	3.79	3.87
11	8	Whitley	US 25W / KY 3041	2.61	1.88	1.58	2.13	2.25
11	9	Knox	KY 3041	3.89	1.75	1.50	2.04	2.10
11	10	Laurel	US 25E	2.05	2.25	1.83	2.46	2.17
11	11	Knox	US 25E	26.25	2.75	1.83	3.46	3.57
11	12	Bell	US 25E	18.60	2.63	2.19	3.37	3.68
11	13	Bell	US 119	15.88	2.63	1.75	2.54	3.68
11	14	Harlan	US 119	39.05	2.63	1.75	3.29	3.68
12	1	Lawrence	US 23	29.00	2.00	1.67	3.21	3.60
12	2	Johnson	US 23	16.87	2.00	1.67	3.12	3.60

District	Segment ID	County(ies)	Route(s)	Centerline Miles	Earthquake Score	Sinkhole Score	Flood Score	Landslide Score
12	3	Johnson	US 460	7.83	1.88	1.58	2.04	2.52
12	4	Floyd	KY 114	11.32	2.13	1.75	2.96	3.68
12	5	Floyd	US 23	22.00	2.25	1.83	3.29	3.83
12	6	Floyd	CR 1659	0.21	1.13	1.08	1.38	1.68
12	7	Floyd	KY 80	14.36	2.13	1.75	2.29	3.68
12	8	Knott	KY 80	20.09	2.00	1.67	2.04	3.60
12	9	Knott	KY 15	9.31	2.00	1.67	2.13	3.53
12	10	Letcher	KY 931 / KY 7	6.81	1.75	1.50	2.13	2.23
12	11	Letcher	KY 15	10.65	2.00	1.67	2.13	2.47
12	12	Letcher	US 119	27.86	2.13	2.19	3.37	3.62
12	13	Letcher	US 23	7.28	2.13	2.19	2.13	2.55
12	14	Pike	US 23	18.11	2.13	1.75	2.29	3.62
12	15	Pike	US 23	14.52	2.38	1.92	3.12	3.78
12	16	Pike	US 119	25.60	2.25	1.83	2.38	3.77
12	17	Pike	KY 194	1.06	1.50	1.33	1.71	2.27
12	18	Pike	US 460	25.26	2.13	1.75	3.29	3.62
12	19	Pike	KY 1789 / KY 1441	1.30	1.38	1.25	1.79	2.18
12	20	Pike	KY 80	2.12	1.38	1.25	1.63	3.05