KENTUCKY TRANSPORTATION CABINET TRANSPORTATION RESILIENCE IMPROVEMENT PLAN

DECEMBER 7, 2022

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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 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 can be implemented to 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 baseline in developing a more robust resilience planning program within the agency. This Plan will be updated as ongoing and future resilience planning activities are completed.

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 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

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 will 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

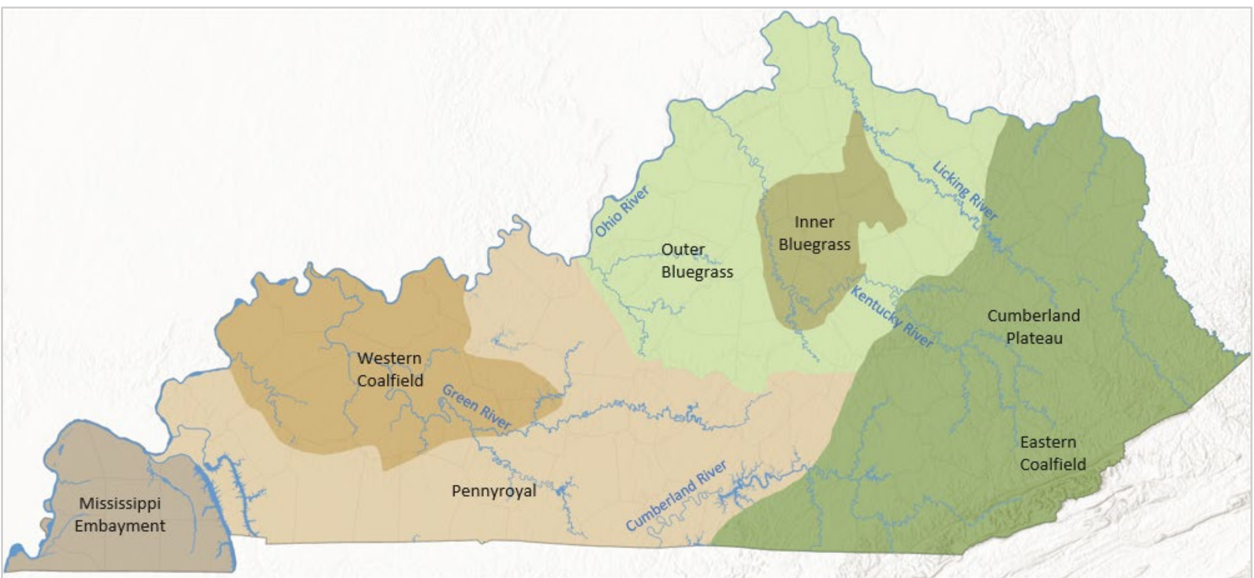
Commonwealth of Kentucky Enhanced Hazard Mitigation Plan (EHMP)

Kentucky is one of fifteen states to have earned FEMA approval for their 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.

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.

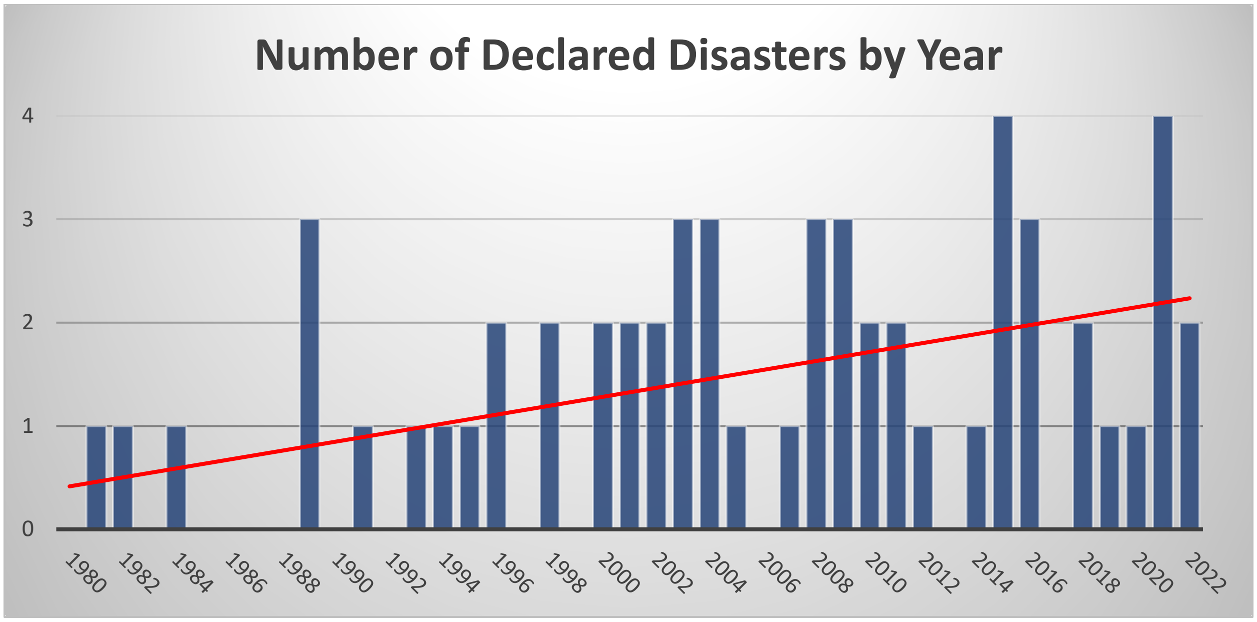
Kentucky's landforms follow a distinct east-west gradient. Elevations are highest and slopes steepest in the east, where the Appalachian Mountains and Cumberland Plateau represent approximately 25 percent of the state's area. The Bluegrass Region, located in the north-central part of the state, includes 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.



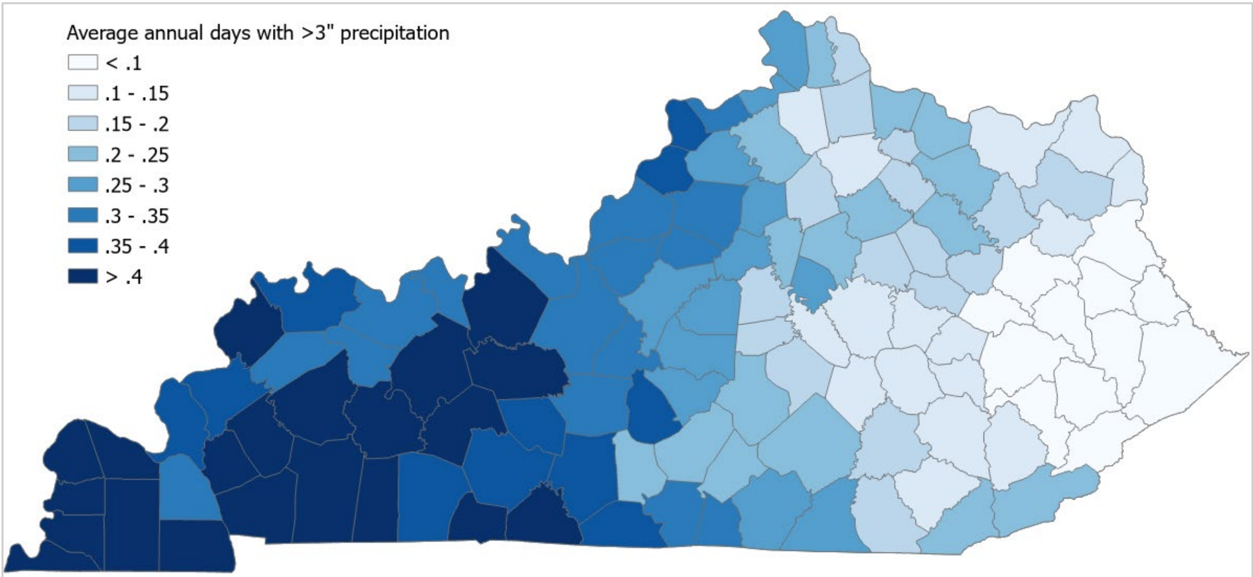
2.1. FLOOD

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.

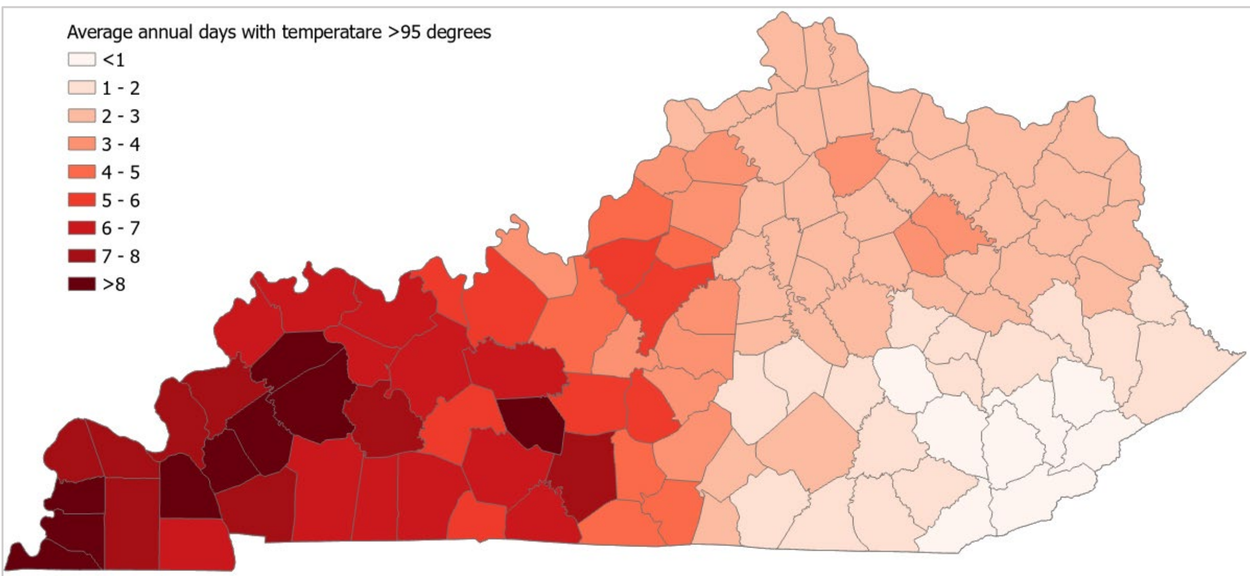
Hail is a type of precipitation that occurs with severe thunderstorms where updrafts of air drive precipitation to higher levels of the atmosphere where it cools, freezes, and then falls as ice. While severe hail can damage vehicles, structures, crops, and livestock, infrastructure damage is limited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

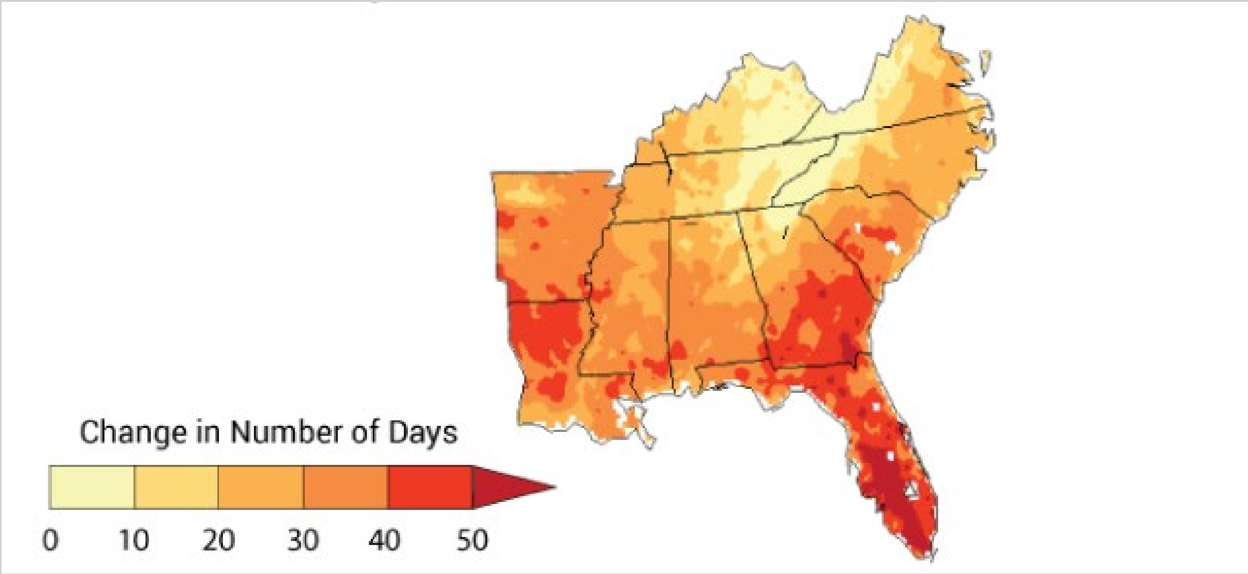
Sinkholes and karst formation can impact highway infrastructure by causing the collapse of roadway surfaces, ditch lines, and bridge foundations. Karst-related flooding can cause temporary road closures, roadway damage, or problems with drainage and rainwater runoff.

2.8. CLIMATE PROJECTIONS

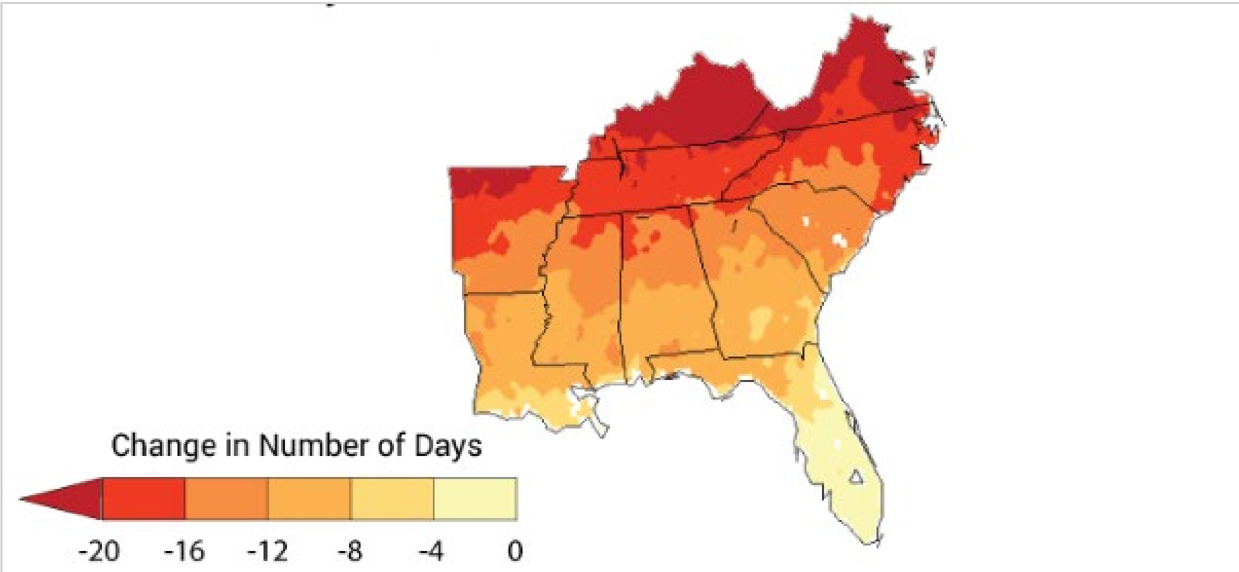
Climate projections provide a useful tool for understanding the frequency with which weather patterns are likely to occur. For transportation planners, this information can help formulate informed decisions regarding mitigation efforts to extreme weather events that may become more severe and occur more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

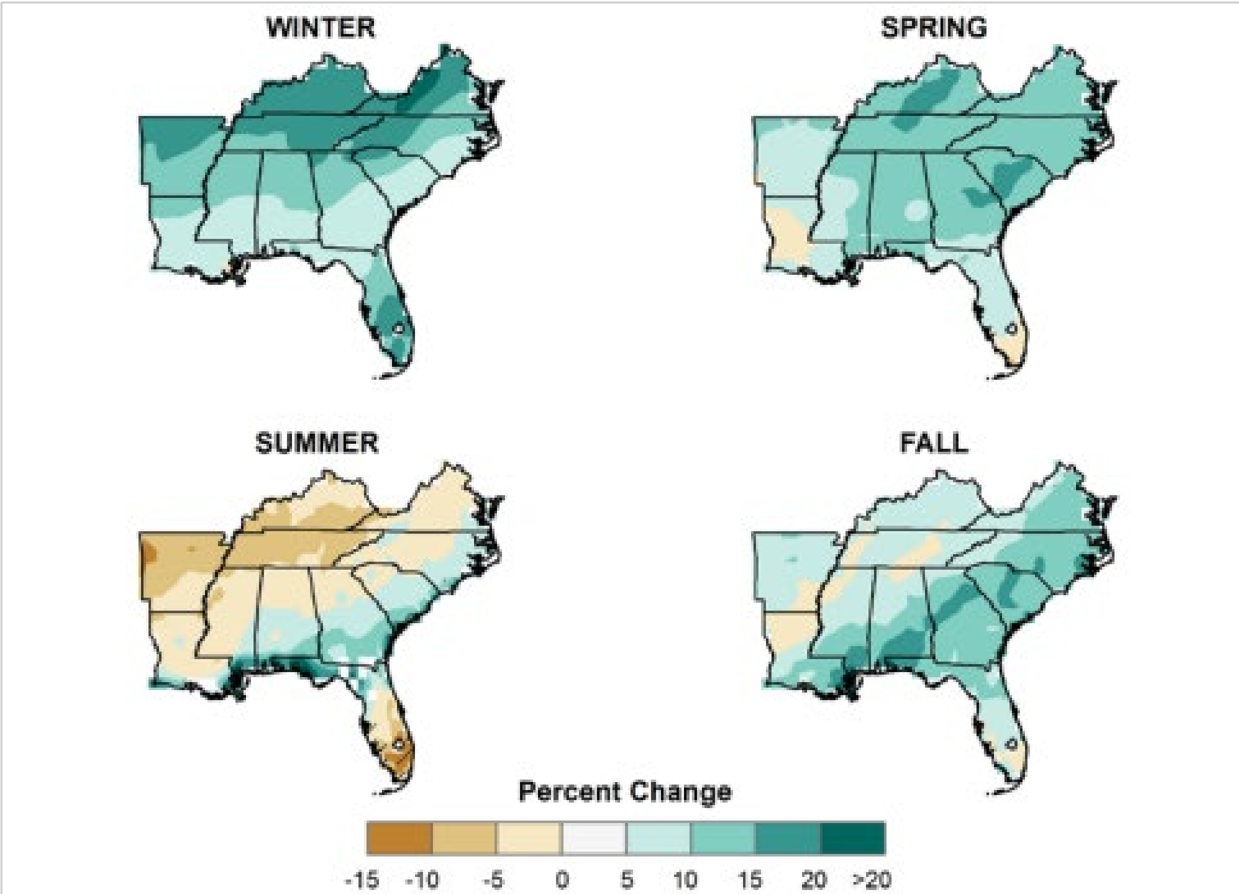


Simulated difference in the mean annual number of days with a minimum temperature lower than 32°F for the Southeast region for the 2041-2070 period with respect to the reference period of 1920-2000. Source: NCA4.

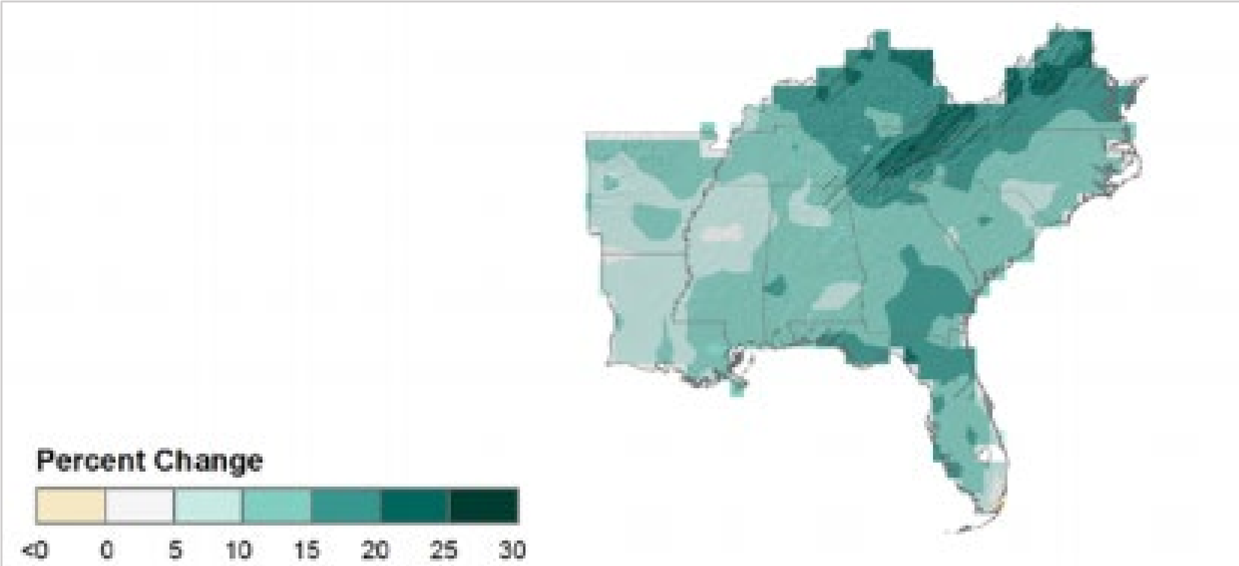
The NCA4 findings also indicate that Kentucky will experience an **increase in annual precipitation**.

- 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.

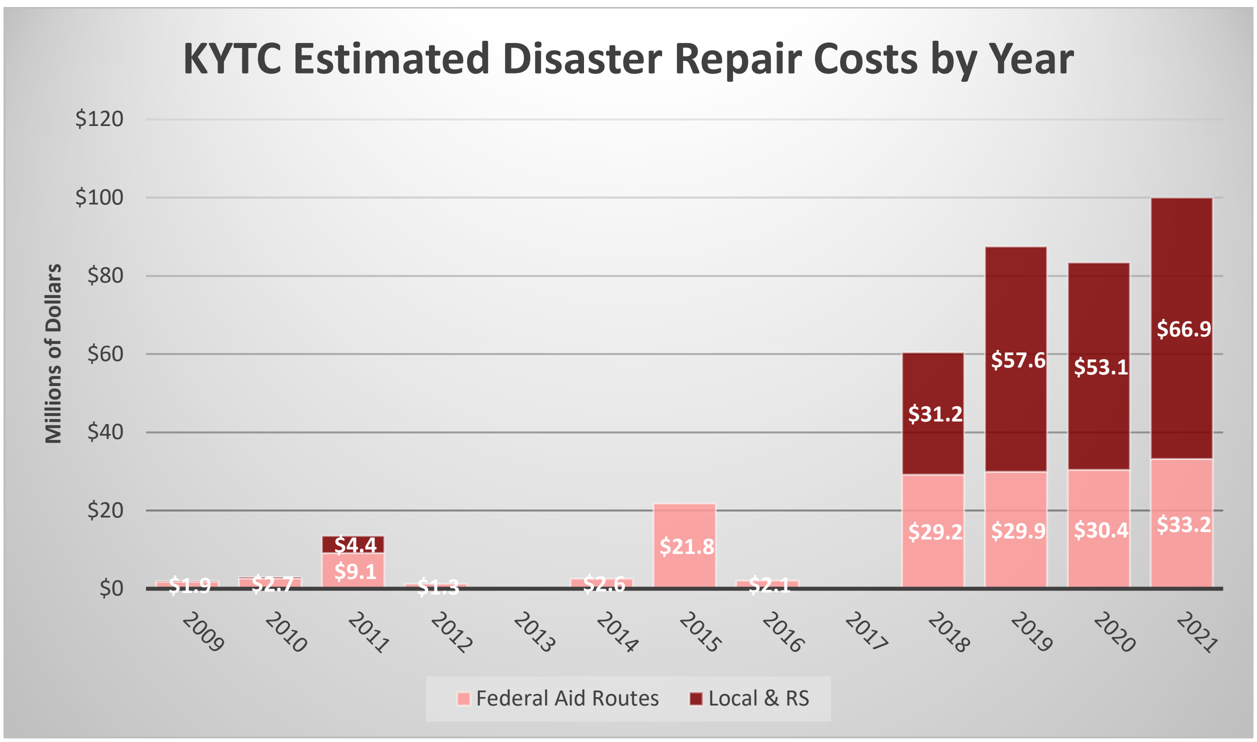


Simulated percentage difference in the mean annual number of days with precipitation of greater than one inch for the Southeast region for the 2041-2070 period with reference period of 1980-2000. Source: NCA4.

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.

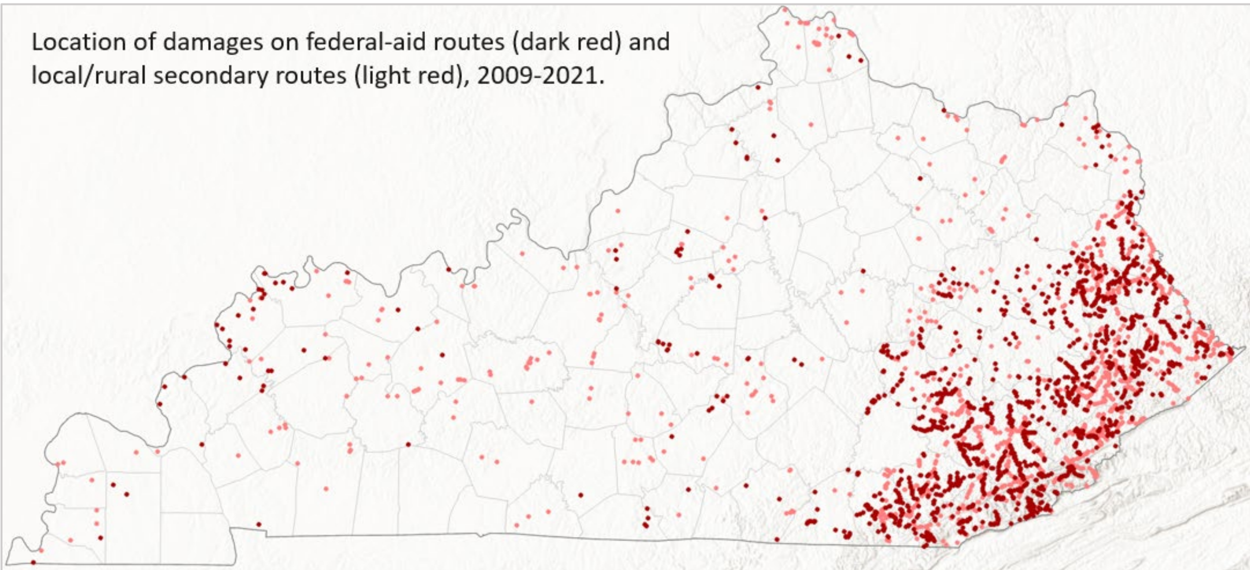
Where available, KYTC also includes in the database estimated costs for highway repairs. Estimated costs for repairs in the database total over $207 million. Of this total, $140 million was for damages to federal-aid routes and $67 million was for local and rural secondary routes. The database also demonstrates 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 2021.

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

In addition to this general assessment, KYTC's National Highway System (NHS), including highway segments, bridges, culverts, and other structures were assessed for risk against the four major hazards of earthquakes, flooding, sinkholes, and landslides. 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. PGA accounts for energy released by an earthquake and how the energy travels through soil and rock.**Centerline miles. ***Includes only those listed in the National Bridge Inventory database.**

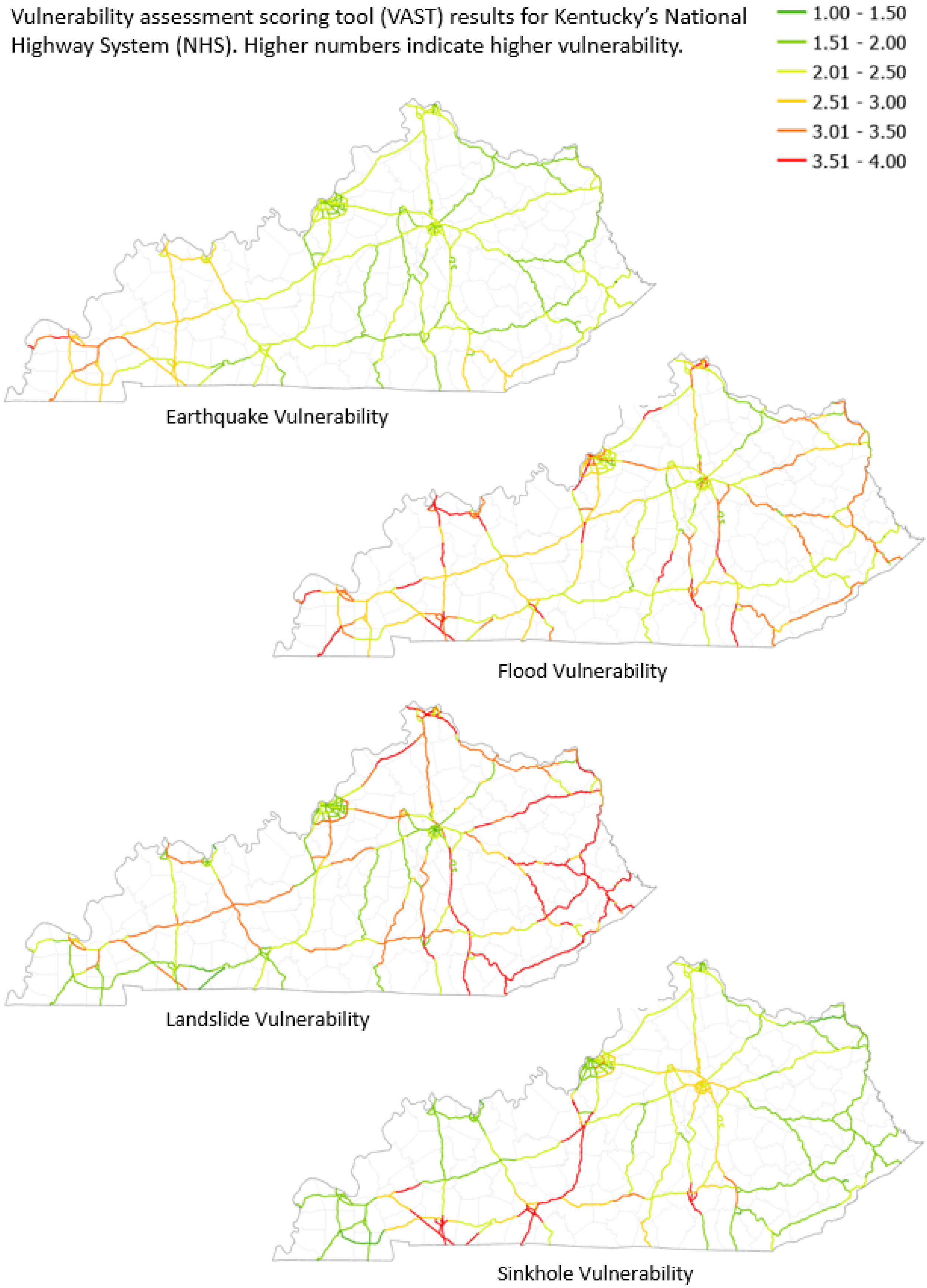
Qualitative data was gathered at a series of workshops held with KYTC personnel at each of the twelve districts. Workshop participants engaged in discussion centered on flood, landslide, and sinkhole hazard mapping for roadway segments throughout their respective districts. This was followed by a series 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.

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.

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 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 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.

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.

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.
- Design approaches. KYTC is conducting research on optimizing asphalt mix designs that will enable the consideration of friction over the service life of the asphalt pavement surface layer. KYTC is also planning to conduct 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.

5.2. PRECIPITATION

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

- Higher average precipitation levels
- More extreme rainfall events
- Increasing 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:

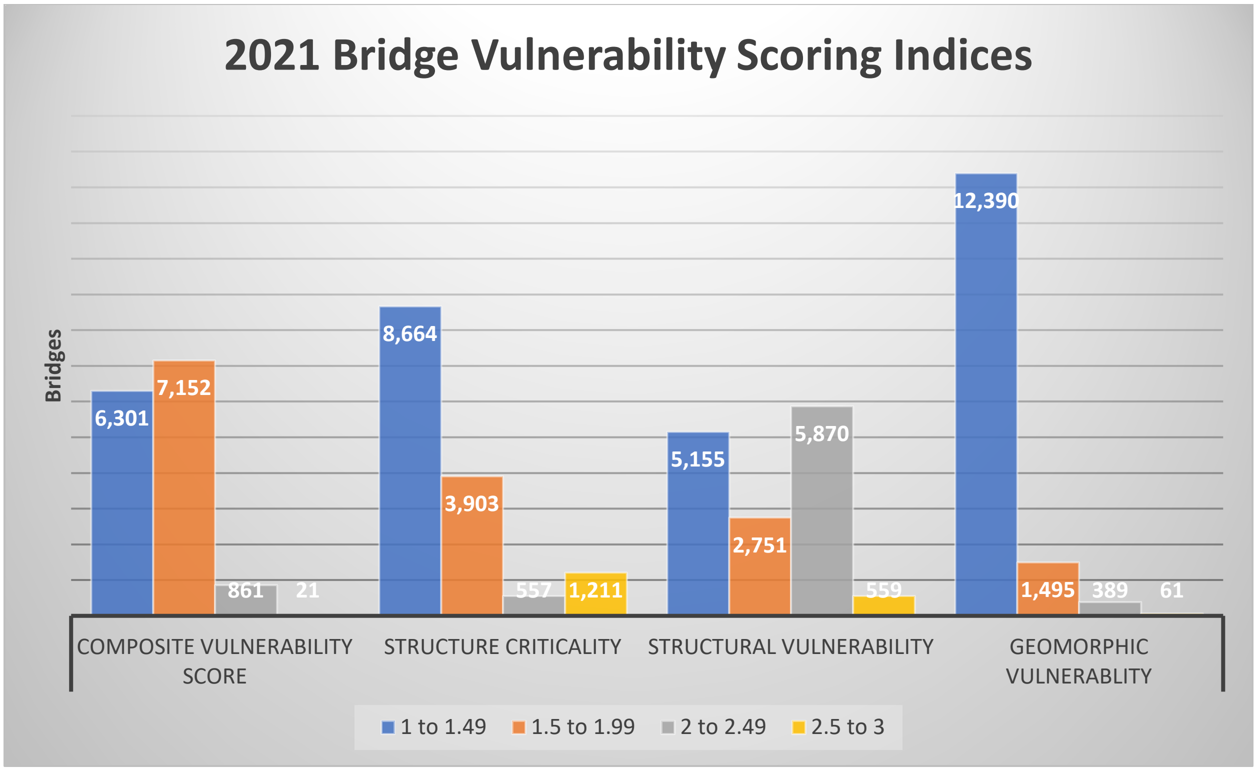
- Construction procedures. KYTC is improving the quality of pavement construction by placing increased emphasis on construction inspection, acceptance, and project delivery.
- Maintenance and operation activities. KYTC has increased efforts to seal cracks and joints in existing pavements and is currently investigating the use of asphalt pavement preservation techniques (e.g., chip seals, fog seals, microsurfacing) that are more effective in reducing permeability. KYTC is also in the process of inventorying various drainage assets using a mobile app system to help identify areas of concern and prioritize project selection.

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

In 2018, KTC/KYTC completed a FHWA pilot project on Extreme Weather, Proxy Indicators, and Asset Management. As part of this pilot project, the research team developed a bridge vulnerability rating methodology that incorporated bridge evaluation data from KYTC. 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 BMS 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.
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. The research will identify transportation asset classes and determine the historical extent to which these classes have been impacted by extreme weather and natural hazards. The research will divide Kentucky into regions and utilize existing climate models to determine projected precipitation and temperature changes over the lifecycle of the asset classes. The research will then use the historical record and the projected precipitation and temperature changes to project the future impacts of extreme weather to transportation assets across the Kentucky regions. The results will be used to calculate the costs of action versus inaction and determine where and how resilience improvements would be most beneficial. The results will help direct KYTC project investments feed directly into future updates of this Transportation Resilience Improvement Plan.