RISK ASSESSMENT

Overview

The 2013 State Hazard Mitigation Plan assesses the Commonwealth of Kentucky's risks over the last three (3) years. This section will be used to understand each identified hazard and as the blueprint for the Commonwealth's mitigation strategy. The risk assessment section has been redesigned from the 2010 plan to capture the newly defined Kentucky Emergency Management (KYEM) hazard categories and hazard classifications developed under Kentucky Revised Statutes (KRS) 39A.010.

These modifications are designed to create a common operating picture for each hazard and threat identified within the organization of KYEM. This process is motivated by KYEM's involvement in the Emergency Management Accreditation Program (EMAP), which is an accreditation program for emergency management organizations.

KYEM identified six (6) hazard categories and organized each of the KRS 39A.010 identified hazards within their suitable hazard category. This process provided the foundation for the newly defined identified hazards for the 2013 State Hazard Mitigation Plan. The following table describes the transition from the 2010 hazard classifications to the 2013 hazard classifications, along with which KYEM hazard category the 2013 identified hazards are situated within.

	2010 Hazards	2013 Hazards	KYEM Hazard Category
1.	Dam Failure	Dam Failure	Human-Made
2.	Drought	Drought	Severe Weather
3.	Earthquake	Earthquake	Geologic/Earthquake
4.	Extreme Heat	Extreme Temperature	Severe Weather
5.	Flood	Flood	Flood
6.	Hail	Hail storm	Severe Weather
7.	Karst/Sinkhole	Karst/Sinkhole	Geologic/Earthquake
8.	Mine Subsidence	Mine/Land Subsidence	Geologic/Earthquake
9.	Landslide	Landslide	Geologic/Earthquake
10.	Severe Storm	Severe Storm	Severe Weather
11.	Severe Winter Storm	Severe Winter Storm	Severe Weather
12.	Tornado	Tornado	Severe Weather
13.	Wildfire	Forest fire	Natural Hazards (Non-Severe Weather)

The most note-worthy changes have occurred with Extreme Temperature, which was Extreme Heat. The newly formed Extreme Temperature category will now include extreme cold as well as extreme heat. Some other minor changes have occurred in the naming conventions of some of the hazards. This was directly related to creating a standard naming convention based on the KRS 39A.010 hazard classifications. Hail has changed to Hail Storm, Wildfire has changed to Forest Fire, and Mine Subsidence has been changed to Mine/Land Subsidence.

The 2013 risk assessment section was developed by KYEM and their long-standing partnership with the University of Louisville's Center for Hazards Research and Policy Development (CHR). While developing the previous plans, best available data was used for the Risk Assessments. To enhance and update the 2013 plan, enhanced detailed data was required in order to better utilize GIS capabilities and to perform an accurate risk assessment to indicate areas of vulnerability to each identified hazard across the entire Commonwealth.

The flow of the 2013 risk assessment section follows the same format as the 2010 State Hazard Mitigation Plan. This format provides answers to all of the required components of the State Hazard Mitigation Plan Crosswalk "Risk Assessment".

- Identifying Hazards: 44 CFR §201.4(c)(2)(i)
- Profiling Hazards: 44 CFR §201.4(c)(2)(i)
- Assessing Vulnerability by Jurisdiction: 44 CFR §201.4(c)(2)(ii)
- Assessing Vulnerability of State Facilities: 44 CFR §201.4(c)(2)(ii)
- Estimating Potential Losses by Jurisdiction: 44 CFR §201.4(c)(2)(iii)
- Estimating Potential Losses of State Facilities: 44 CFR §201.4(c)(2)(iii)

As in 2010, KYEM and CHR developed a "Hazard Risk Assessment Overview" for each hazard sequentially. This format allows the reader to see each step of the risk assessment associated with each hazard to improve flow and comprehension.

Throughout the risk assessment, Geographic Information System (GIS) spatial data provides the baseline for the 2013 plan. GIS provides the architecture to facilitate an inventory of assets and hazards as well as providing the platform to calculate vulnerabilities and losses. The maps developed through GIS production are used whenever possible to convey where spatially defined vulnerable areas are located. The maps created from this production also provide a visual tool for analysis of the data. The information developed throughout this section was guided and developed using best available data and modeling techniques.

Uncertainties are inherent in any vulnerability/risk assessment and loss estimation methodology, arising in part from incomplete scientific knowledge concerning natural and man-made hazards and their effects on the built environment. Uncertainties can also result from approximations and simplifications that are necessary for a comprehensive analysis (such as incomplete/duplicate inventories, socio-economic data, loss data or occurrence data). These uncertainties are particularly prevalent when

completing a state-wide risk assessment. CHR reviewed multiple sources of data to make an informed decision on each data set used for each identified hazard. Each source of data (occurrences, losses etc.) routinely will contrast from each other. CHR attempted to use standard/analogous data sets in order to maintain an apple to apples comparison of each identified hazard.

Identifying Hazards: Overview

This section provides a complete overview and definition of each hazard that could potentially affect the state. A complete understanding of each hazard better prepares decision makers, local agencies and residents on the causes of, potential damages contributed to, and possible scenarios of each hazard.

REQUIREMENT
§201.4(C)(2)(I):

The Commonwealth of Kentucky shall include an overview of the type of all natural hazards that can affect the state.

Due to its diversified geology and geographical setting, the state of Kentucky is vulnerable to a wide array of natural hazards which threaten life and property. To identify the appropriate hazards for the 2013 plan, CHR reviewed the historical impacts of all hazards affecting the commonwealth along with the following items:

- Past Presidential, Major Disaster and Emergency Declarations
- Annual rates of hazard occurrences
- Dollar losses to date attributable to past disasters
- Comparison to local plans and previous state plans (See ***Appendix 3-1*** "Local Plans Identified Hazards")

As mentioned, the 2013 plan marginally altered the listing of identified hazards. Also, the hazards have been categorized within the newly formed KYEM hazard categories. The hazards are chronicled within their KYEM hazard categories instead of alphabetical order, as in the past.

The identified hazards for the 2013 plan are as follows:

2013 Hazards	KYEM Hazard Category
1. Flood	Flood
2. Earthquake	Geologic/Earthquake
3. Karst/Sinkhole	Geologic/Earthquake
4. Mine/Land Subsidence	Geologic/Earthquake
5. Landslide	Geologic/Earthquake
6. Dam Failure	Human-Made
7. Forest fire	Natural Hazards (Non-Severe Weather)
8. Drought	Severe Weather
9. Extreme Temperature	Severe Weather
10. Hail Storm	Severe Weather
11. Severe Storm	Severe Weather
12. Severe Winter Storm	Severe Weather
13. Tornado	Severe Weather

Each hazard will have an individual "Identify" section where the hazard will be defined followed by the remaining components of the "Hazard Risk Assessment Overview".

Profiling Hazards: Overview

As noted in the last section, due to Kentucky's varied geology, climate, and geographical setting, the state is vulnerable to a wide array of hazards (see section titled, Identify Hazards) that threaten life and property. The profiling hazards section describes each hazard's past, present and future effects on the Commonwealth through completing an extensive overview.

REQUIREMENT §201.4(C)(2)(I):

The Commonwealth of Kentucky shall include a location of all natural hazards that can affect the State, including information on previous occurrences of hazard events, as well as the probability of future hazard events, using maps where appropriate … .

The 2013 profiles have been created using the best available data from a variety of resources, including but not limited to the National Climatic Data Center (NCDC), National Weather Service (NWS), National Oceanic and Atmospheric Administration (NOAA), SHELDUS, Kentucky Office of Geographical Information, Kentucky Geological Survey (KGS), Kentucky Emergency Management Agency (KYEM), Kentucky Division of Water (KDOW), Kentucky Division of Forestry, Division of Abandoned Mine Lands (AML), USGS, FEMA, multiple other state and local agencies, and local newspaper articles, as well as the approved 2010, 2007, and 2004 Kentucky State Hazard Mitigation Plan and local hazard mitigation plans.

The profile section provides the historical context for identifying the hazards. The following table displays past presidential declaration occurrences along with the Public Assistance and Individual Assistance distributed. These Disaster Declarations and assistance numbers provide an understanding of the hazards disrupting Kentucky's communities.

KY Presidential Disaster Declarations 2005-2013

Disaster Declaration	Declatoration Date	Individual Assistance Applications*	Individual Assistance Amount Disbursed*	Total Public Assistance Grants**	Dam Failure	Drought	Earthquake	Extreme Temp.	Flood	Hailstorm	Karst/Sinkhole	Land/Mine Subsidence	Landslide	Severe Storm	Severe Winter Storm	Tornado	Forest Fire
DR-4057	February 29- March 3, 2012	5,746	$ 10,378,250	$ 12,438,032					x					x		x	
DR-4008	June 19 - 23, 2011	820	$ 2,886,169	$ 2,428,630					x					x		x	
DR-1976	April 12- May 20, 2011	2,330	$ 9,239,830	$ 31,886,410					x					x		x	
DR-1925	May 25, 2010	2,548	$ 10,602,929	$ 6,372,211					x				x	x			
DR-1912	May 1, 2010	7,343	$ 20,784,629	$ 22,522,805					x				x	x			
DR-1841	May 3-20, 2009	5,543	$ 15,117,446	$ 34,825,014					x				x	x		x	
DR-1818	January 26 - February 13, 2009	not requested	not requested	$ 213,768,779					x						x		
DR-1802	September 14-15, 2008	not requested	not requested	$ 18,821,452										x			
DR-1855	August 4, 2008	12,406	$ 17,701,502	$ 3,791,750					x					x			
DR-1757	April 3-4, 2008	not requested	not requested	$ 3,499,938					x				x	x		x	
DR-1746	February 5-6, 2008	1,032	$ 1,466,605	$ 4,954,738					x					x		x	
DR-1617	December 1, 2005	399	$ 459,715	not requested										x		x	

*Source: KY Division of Emergency Management, Recovery Branch. IA Disaster Summary by County.
**Source: FEMA.gov

Understanding risk and each hazard's potential effect on the Commonwealth is imperative to the mitigation strategy and provides the information needed to produce an effective risk assessment. In order to accomplish this, CHR captured data on hazard occurrences and losses, which are commonly used to capture risk. The following "Risk Matrix" table provides quantitative data that portrays which hazards have been the most destructive based on occurrence and loss data. CHR reviewed multiple sources of hazard data for each identified hazard in order to create the Risk Matrix table. The table provides a state-wide overview of each hazard and provides a baseline to be used by the state hazard mitigation council to prioritize which hazards should receive the most consideration when justifying potential mitigation projects.

Risk Matrix							
Hazard Type	Time Period	Range – Years of Data Collection	Occurrences	Total Losses	Annual Rate of Occurrence	Average Losses	Average Annual Loss
Flood	1960-2013	53	5,934	$2,301,445,697	111.96	$387,841	$43,423,504
Earthquake	1960-2011	53	1	$2,763,158	0.02	$2,763,158	$52,135
Karst/Sinkhole	Unknown	Unknown	101,632	$0	Unknown	Unknown	Unknown
Mine/Land Subsidence	1981-2013	32	133	$5,550,000	4.16	$41,729	$173,438
Landslide	1975-2013	38	1,393	$28,365,706	36.66	$20,363	$746,466
Dam Failure	1973-2013	30	13	$0	0.43	Unknown	Unknown
Forest Fire	1997-2012	25	22,467	$41,250	898.68	$2	$1,650
Drought	1960-2013	53	121	$301,317,375	2.28	$2,490,226	$5,685,233
Extreme Temperature	1960-2013	53	1,175	$1,141,306	22.17	$971	$21,534
Hail Storm	1960-2013	53	4,882	$983,340,017	92.11	$201,422	$18,553,585
Severe Storm	1960-2013	53	21,481	$898,499,257	405.30	$41,828	$16,952,816
Severe Winter Storm	1960-2011	53	3,951	$435,706,556	74.55	$110,278	$8,220,878
Tornado	1960-2013	53	11,36	$1,020,237,467	21.43	$898,096	$19,249,764
TOTALS			164,319	$5,978,407,789		$6,955,913	$113,081,003

Source: SHELDUS, NCDC, National Dam Safety, Ky. Division of Forestry, Division of Abandoned Mine Lands and Kentucky Geological Survey

The Risk Matrix table provides a view of the risk each hazard poses to the Commonwealth. Combining the average occurrence and loss statistics formulates an average annual loss for each hazard, and therefore provides a model for loss estimation by hazard. Clearly, the flood hazard has the most potential to do damage to the Commonwealth with tornado, hail, and severe storm posing a high risk as well.

It is important to note, that hazards without an average annual risk should still be considered a threat to the Commonwealth. This is mainly caused by lack of current data (occurrences or losses) for some of the hazards. Importantly, hazards can have a very low probability but a potentially high magnitude of losses (Earthquake). Please note, the Risk Matrix data will be used for multiple purposes throughout the risk assessment section.

Profiling Hazards

To disseminate the profile information, CHR developed a common format for each hazard. The “Profile Risk Table” summarizes key data elements that allow the end user to view the hazard. Below is an example of the “Profile Risk Table” along with an explanation of each data element.

Hazard: Profile Risk Table	
Period of occurrence:	When does this hazard occur?
Number of events: (Year - Year)	Number of hazard events in Kentucky based on county occurrences for each hazard. So you could have one state event count as 50 county-level events within this data capture.
Annual Rate of Occurrence:	Expected annual number of state-wide occurrences per year based on county-level occurrence data.
Warning time:	Average warning time for this type of hazard.
Potential impacts:	The potential impacts this hazard could produce.
Recorded losses:	Amount of damages captured within Kentucky for each hazard (This data is very diverse).
Annualized Loss:	The expected annual loss state-wide per year from each hazard.
Extent:	Worst case scenario based on historic data.

Assessing Vulnerability by Jurisdiction: Overview

The Assessing Vulnerability by Jurisdiction section uses data from national, state, and local data sources and was created using best available data and modeling techniques. The 2013 assessing vulnerability section provides two (2) levels of assessment. KYEM desired a county-level assessment along with a more refined model. The two models created for the 2013 State Hazard Mitigation Plan are based on the University of Louisville's Center for Hazards Research and Policy Development (CHR) recognized expertise in the field. These models have been used for multiple states, local and university hazard mitigation plans.

REQUIREMENT §201.4(C)(2)(II):

The Commonwealth of Kentucky shall include an overview and analysis of the State's vulnerability to the hazards described in this paragraph (c)(2), based on estimates provided in local risk assessments as well as the State risk assessment. The State shall describe vulnerability in terms of the jurisdictions most threatened by the identified hazards, and most vulnerable to damage and loss associated with hazard events. State owned critical or operated facilities located in the identified hazard areas shall also be

The models are flexible and can be adjusted to fit the data and needs of particular consumers. These models provide an understanding of relative risk and vulnerabilities from hazards across Kentucky. Uncertainties are inherent in any vulnerability/risk assessment, arising in part from incomplete scientific knowledge concerning hazards and their effects on the built environment. Uncertainties can also result from approximations and simplifications that are necessary for a comprehensive analysis (such as incomplete or duplicate inventories, socio-economic data, loss data, or occurrence data).

The 2013 Risk Assessment incorporates multiple methods and data resources, and integrates them into specific models geared toward answering the questions asked by FEMA in this section. FEMA requires state partners to assess each jurisdiction's vulnerability to their population, property, infrastructure, critical facilities, and state owned facilities.

To gain an understanding of vulnerabilities and loss estimations throughout the state CHR completed a review of the current local plans. This review mainly influenced the determination of identified hazards (See ***Appendix 3-1*** "Local Plans Identified Highest Risk Hazards"). As discussed in the 2010 plan, several of the local plans have begun using the State's Risk Assessment model to complete the risk assessment sections of their plans.

This has been encouraged at the State level and will continue to be pushed as the State expands it use of the Community Hazard Assessment Mitigation Planning System (CHAMPS) system. With CHAMPS v2, locals will be able to add their local data occurrences inside the system through a module called Significant Incident Events (SIE). These SIEs will start building a significantly better picture of where hazard events occur in the Commonwealth. As this data matures it will be used to provide an enhanced data resource for State and local risk assessments as well as for Benefit Cost calculations. Also, in CHAMPS v2, KYEM and CHR are developing a Risk Assessment Module that will capture local data inputs and eventually drive State data outputs. The future of the Commonwealth's risk assessment methodologies is very positive. Comparing different risk/vulnerability assessments creates a significant challenge, due to the fact that the outputs are not created equally. Of course this is one of the main reasons that the State has been pushing for a common risk assessment model that can be used at the State level as well as the local level.

It is important to note that CHR did use local exposure data created at the local level for the State's vulnerability model. This included several of the Exposure Score variables including: Critical Facilities, Utilities, and Transportation Infrastructure. This data is crucial for creating an accurate account of what is potentially exposed to each hazard and therefore an important part of the State's Vulnerability Assessment Model. The local data capture will continue as several of the facilities identified are maintained and updated by our local partners. These data inputs will also become easier to capture through CHAMPS v2's Infrastructure Module. This specific module allows users to add local, regional, and State infrastructure into the system through a standard data format. This format has been developed to fold into the Risk Assessment model in the future.

As mentioned before, this iteration of the Kentucky Risk Assessment has two (2) models. One created for county-level review and one created for a more granular intake, which can also be used for local hazard mitigation plans. The county-level risk assessment will be identified as the County-Level Risk Assessment model and the more refined model will be identified as the Grid-Level Risk Assessment model. Creating these two (2) models provide different perspectives for KYEM to use for various purposes.

Grid-Level Risk Assessment Model

A very important step in creating a Vulnerability Assessment Model is to define the planning area. Through the creation of the last three (3) State Hazard Mitigation Plans, KYEM and CHR have continued to develop a risk assessment that has become more granular. During the creation of the 2010 plan CHR used its knowledge of creating local plan vulnerability assessments and created a statewide census block level assessment.

This model produced a more equal playing field but still tended to get skewed in areas that were more rural, based on the fact that the census blocks within these areas were typically larger in size. The lack of equal area distribution caused the census block model to still have some particular issues when comparing individual census blocks due to the unequal size of each census block.

During the 2013 development of the plan, CHR was looking for a planning area that provided a granular approach as well as providing an even playing field in terms of equal area distribution. CHR and KYEM decided to go with a 1 Kilometer (KM) Military Grid Reference System (MGRS) for their planning areas of capture for the entire State. The MGRS was chosen based on the equal area distribution of each grid cell and the fact that the military based grid system can also be used during response and recovery efforts. This model promotes usage at the State level as well as the local level. The Grid-Level Risk Assessment Model specifically provides the following improvements:

1. Equal area calculations based on each unit being equal sized
2. Allows better comparisons between planning areas in different parts of the State
3. Potential for better policy decisions and dollar allocation
4. Improved visual interpretations
5. Enhanced tools for local planning usage
6. Military grid provides enhanced usage during response and recovery

The Grid-Level Risk Assessment methodology allowed the state to provide enhanced data for use in local plans and provide policy and decision makers a refined view of where risk is located and what areas need mitigation. There are a total of 106,178 individual grids across the Commonwealth. CHR and KYEM's goal is to provide local leaders with a useful assessment model. The model is also being developed to facilitate assessment standardization and with the realization of locals eventually populating the system with their local data.

Methodology

There are multiple models that attempt to determine risk and hazard vulnerability. KYEM relied heavily on CHR's knowledge of the "Risk Assessment" research field to develop the Vulnerability Assessment Model used for the State Hazard Mitigation Plan.

In order to follow and comprehend the Hazard Vulnerability Assessment Model the following definitions are very important to comprehend:

Important definitions associated with this vulnerability assessment model:

- **Hazard Identification**: Anything which either threatens the residents of a community or the things that they value
- **Exposure**: A community's assets: people, property, essential facilities, and infrastructure potentially exposed to a hazard
- **Vulnerability**: What part of an "exposure" is at "risk" to each "hazard"

CHR's staff researched and conducted test runs to develop an updated methodology. The revised model relies heavily on GIS spatial analyses and provides the user with several layers of integrated information which can be used individually to display different planning scenarios. This approach enabled the creation of a Hazard Vulnerability Score for each hazard.

Model

Hazard Vulnerability Score = Exposure Score + Hazard Score

When measuring vulnerability, CHR first measured what would be exposed to each hazard. Exposure Score was built on multiple layers of data and provides the foundation for assessing vulnerability. For this model the exposure score was comprised of these three (3) variables:

1. Population Score
2. Property Score
3. Critical Infrastructure Score

Exposure Score

Exposure Score = Population Score + Property Score + Critical Infrastructure Score

Definition of Variables

1. ***Population Score*** – To develop an improved population density model for use within the MGRS 1 KM grid system, CHR used a method called Dasymetric Mapping (http://pubs.usgs.gov/fs/2008/3010/fs2008-3010.pdf). This method of mapping population data uses an aggregation area model using a combination of population data and land cover data. For this model, 2010 census block data was used to capture population and 2006 USGS National Land Cover Database (NLCD2006) was used for land cover data. Basically, this type of mapping assigns population density based on different types of land cover (high density, low density, non-urban inhabited, uninhabited). Each one of the specific land cover areas is assigned a population number based on the census blocks population. This method attempts to distribute a census blocks population number to where there is actual land cover, instead over the entire area. This data was then aggregated to each 1 KM MGRS grid for consumption. Each grid within Population Score is scored from 0-1. This score is multiplied by .33 so it accounts for 33% of the composite Exposure Score.

2. ***Property Score*** – Comprised of 2010 census block group total household value (# of housing units x average household value) aggregated to the 1 KM MGRS grid. This data was then scored 0-1 and multiplied by .50 so it accounted for 50% of the Property Score. Next, a total number of businesses acquired from ESRI's business analyst were then counted within each 1 KM MGRS grid. This data was then scored 0-1 and multiplied by .50 so it accounted for 50% of the Property Score. These two (2) scores were then added together to create the composite Property Score. This score is multiplied by .33 so it accounts for 33% of the composite Exposure Score.

3. ***Critical Infrastructure Score*** – Comprised of multiple Critical Facilities (points and lines) across Kentucky. This data was retrieved from KYEM, Division of State Risk and Insurance, ESRI, Kentucky Infrastructure Authority, Kentucky office of Geographic Information (OGI), Kentucky Transportation Cabinet and Public Service Commission. This included data ranging from several different classes of GIS points and lines. The point data included the following:

   fire stations, police stations, prisons, primary schools, hospitals, emergency operation facilities, nursing homes, public health facilities, emergency medical service facilities, sewer treatment facilities, sewer package treatment and lift station facilities, water pumps, water treatment plants, sewage treatment plants, water tanks, electric power plants, pressure and storage gas facilities, refinery and storage oil facilities, airport facilities, Highway bridges, rail facilities EPA FRS Facilities and State owned facilities.

The total numbers of critical facilities (points) were then counted within each 1 KM MGRS grid. This data was then scored 0-1 and multiplied .80 so it accounted for 80% of the Critical Infrastructure Score. The line data included the following:

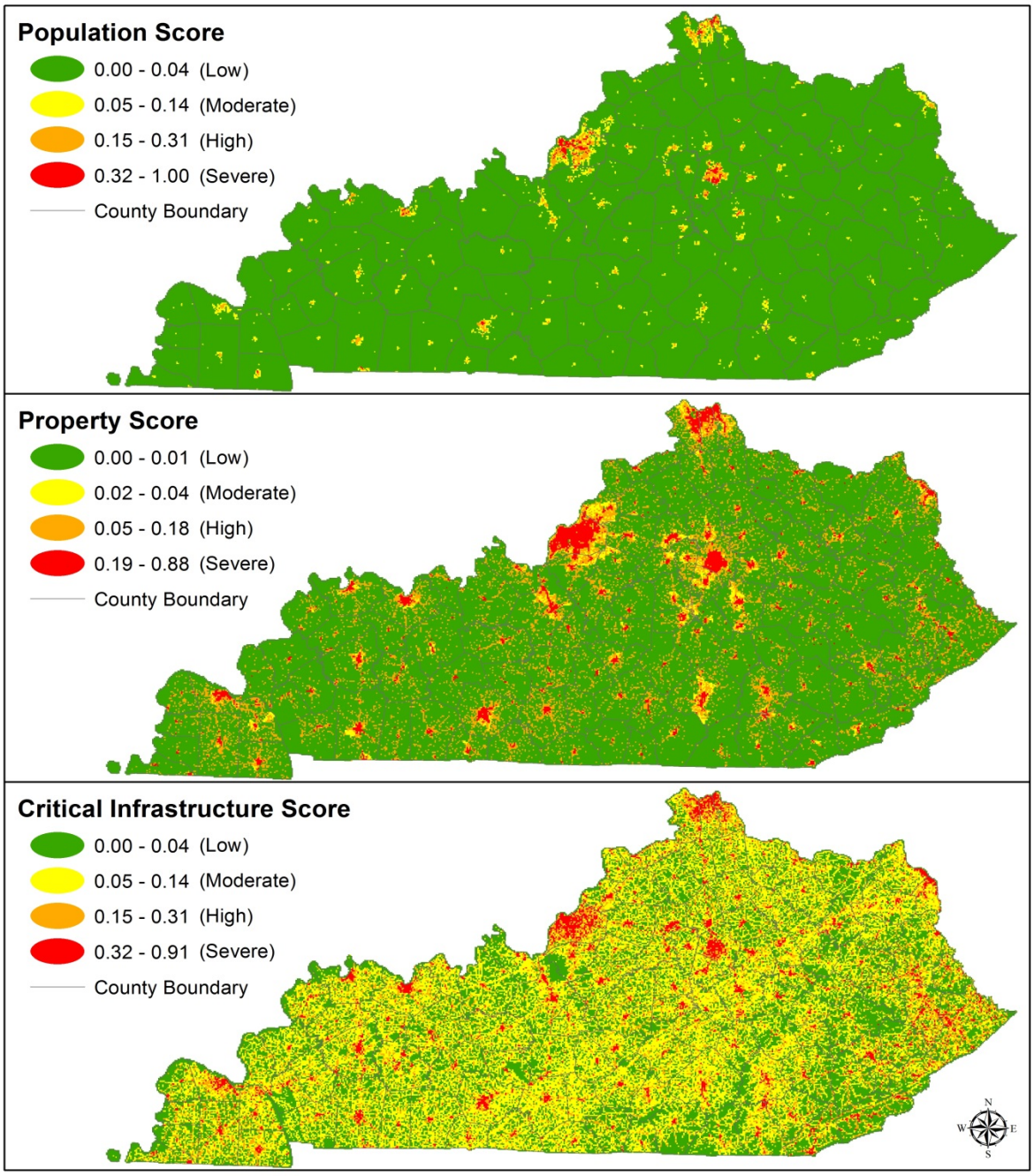
> *sewer lines, water lines, power transmission lines, pipelines, Kentucky Transportation Cabinet all roads mapped and railroads.*

The total length of each line was captured within each 1 KM MGRS grid and combined. This data was then scored 0-1 and multiplied by .20 so it accounted for the other 20% of the Critical Infrastructure Score. These two (2) scores were then added together to create the composite Critical Infrastructure Score. This score is multiplied by .33 so it accounts for 33% of the composite Exposure Score.

The Exposure Score places the asset variables into the Hazard Vulnerability Score. This data is critical for Emergency Managers to use in order to comprehend where high concentrations of need could be during or before a disaster. Each exposure variable was calculated and scored 0-1 and then multiplied by .33 to create a weighted score of 33% for each category. Once all three (3) were added together to create the composite exposure score they were broken into four (4) categories, using Natural Breaks classification The four (4) categories provide different levels of severity displayed on each map:

1. Low
2. Moderate
3. High
4. Severe

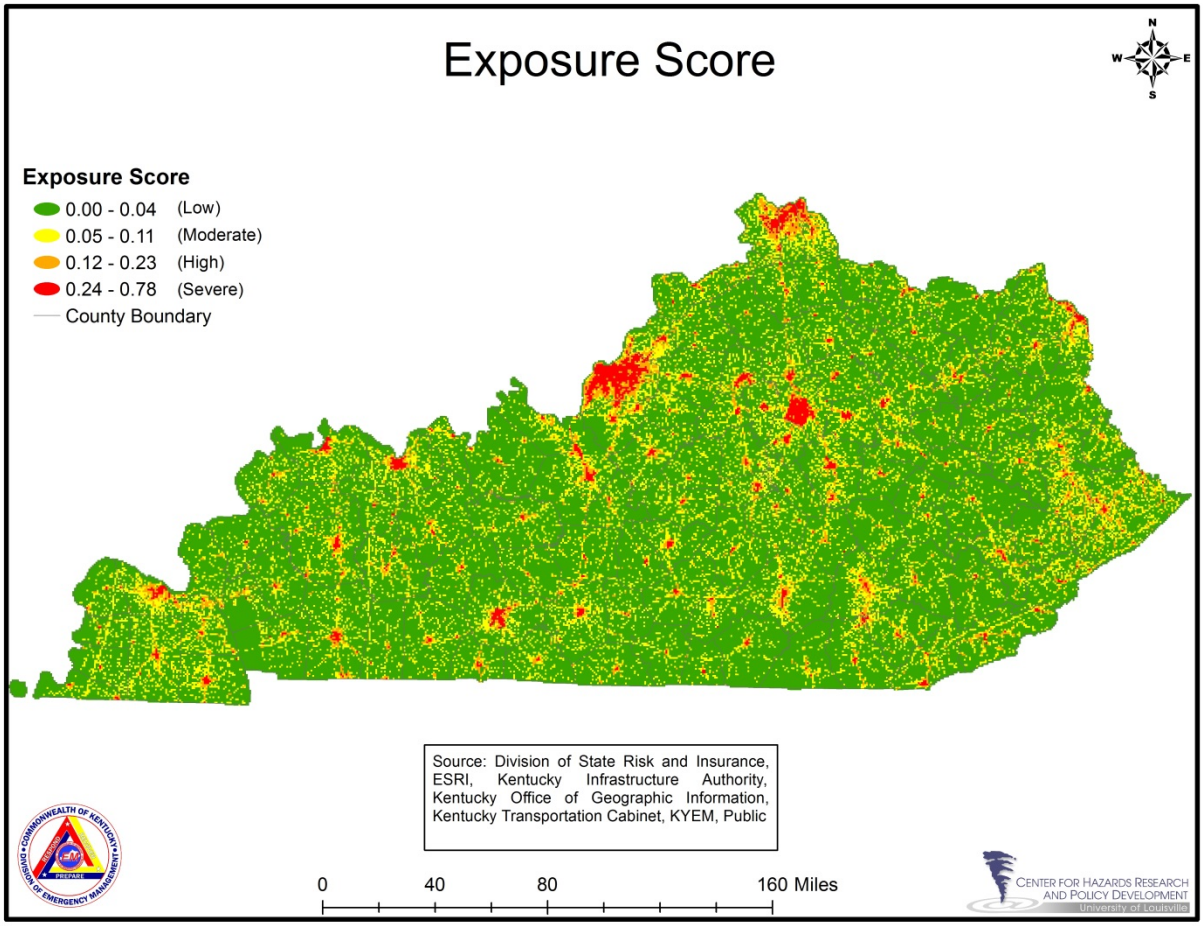
The following displays each Exposure Score component followed by the composite Exposure Score.



Source: Division of State Risk and Insurance, ESRI, Kentucky Infrastructure Authority, Kentucky Office of Geographic Information, Kentucky Transportation Cabinet, KYEM, Public Service Commission, USGS, and the US Census Bureau.

0 30 60 120 Miles

CENTER FOR HAZARDS RESEARCH AND POLICY DEVELOPMENT
University of Louisville



Hazard Score

The Hazard Score assigns a hazard variable to the Hazard Vulnerability Score. The Hazard Score varies with each hazard due to the fact some hazards have area boundaries for analysis, like flooding, while numbers of occurrences are best for those hazards occurring anytime or anyplace, like severe storms. Due to the variation on how each Hazard Score was calculated a description for each hazard will be provided within each “Hazard Risk Assessment Overview”.

After the Exposure Score and the Hazard Score were determined, the equation was set into motion to produce a Hazard Vulnerability Score for each identified hazard. The Hazard Vulnerability Scores contain some bias toward the more populated areas in the state. This is due to a correlation between more populated areas and their tendency to have higher numbers of critical facilities, properties, transportation facilities, etc. This resulted in higher populated areas having greater exposure in general. However, with the data provided, other equations can be developed with or without one or more variables, or a different weighting system. The goal of this model was to assess the

most vulnerable areas throughout the state. Given the most populated areas have the most at risk, this model achieved that goal.

County-Level Risk Assessment Model

The county-level model provides assessments of which counties throughout the State are experiencing the most risk. This display of the data provides a comparative view of each county. This model also ties to the current Risk Assessment Module within CHAMPS, which captures risk currently at the county-level.

REQUIREMENT §201.4(C)(2)(III):

The Commonwealth of Kentucky shall include an overview and analysis of potential losses to the identified vulnerable structures, based on estimates provided in local risk assessments as well as the State risk assessment. The State shall estimate the potential dollar losses to State owned or operated buildings, infrastructure, and critical facilities located in the identified hazard areas.

To create the County-Level Risk Assessment Model, CHR used the Risk Matrix data to convey risk. Specifically, the Annual Rate of Occurrence and the Average Annual Loss categories were used. For hazards that averaged over a million dollars in losses per year at the State level were assessed using each county's Average Annual Loss number (See ***Appendix 3-2*** "Hazard Average Annualized Loss" for County Average Annual Loss numbers). For those hazards that did not have a noteworthy amount of loss data it was decided to use their Annual Rate of Occurrence numbers (See ***Appendix 3-2*** "Hazard Average Annualized Loss" for County Annual Rate of Occurrence numbers).

A complete description of each hazard's County-Level Risk Assessment will be provided within each "Hazard Risk Assessment Overview".

Estimating Potential Losses of Jurisdictions and State Facilities

A key piece to any risk management system is to understand a community's potential losses. CHR decided to capture loss using two (2) different methodologies. The methodologies differ in that one is a county-level assessment, which was used to capture jurisdictional potential loss, where the other is geo-spatially specific, which was used to capture both vulnerability and loss estimates on State facilities. The two (2) models that were used for the 2013 State Hazard Mitigation are the ***Average Annualized Loss Model*** and the ***Hazard Boundary Overlay Loss Estimation Model***.

As has been mentioned before, uncertainties are inherent in any loss estimation methodology, arising in part from incomplete scientific knowledge concerning natural hazards and their effects on the built environment. Uncertainties can also result from approximations and simplifications that are necessary for a comprehensive analysis (such as incomplete or duplicate inventories, socio-economic data, loss data, or occurrence data).

Jurisdictional: Average Annualized Loss Model

This model uses annual rate of occurrence data and average losses data to calculate an Average Annual Loss for several of the identified hazards (See Risk Matrix Table). Annual rate of occurrence is based on past occurrences and average losses are based on past losses.

Knowing both the "annual rate of occurrence" and the "average losses" produces the ability to predict an Average Annual Loss for any given year by multiplying the two values together. This model provides a suitable understanding of general loss for each county within the Commonwealth. The model relies on capturing historical event data and therefore it is fundamental that future hazard occurrence data is captured (Occurrence and Loss Data).

It is important to note that hazard occurrence data is what the SIE module within CHAMPS version II is developed to capture. CHR and KYEM has longed recognized some deficiencies in this type of data capture and have used best available data for each hazard. The SIE module will provide specific hazard occurrence data capture at the local level that will provide an enhanced view of real losses that can be used to better estimate potential losses.

As mentioned above, data capture limits the effectiveness of this model. CHR and KYEM were able to acquire sufficient data to develop an Average Annual Loss estimate for the following eleven (11) Hazards:

1. Flood
2. Earthquake
3. Mine/Land Subsidence
4. Landslide
5. Forest Fire
6. Drought
7. Extreme Temperature
8. Hail Storm
9. Severe Storm
10. Severe Winter Storm
11. Tornado.

Currently Karst/Sinkhole and Dam Failure do not have suitable loss data to capture an Average Annual Loss number. However, loss estimates were developed for these hazards through analyzing the property values within each "Severe Hazard Score" grids. This methodology assumed a complete loss of all property within each Karst and Dam Failure Severe Hazard Score grid (See ***Appendix 3-3*** *"Karst & Dam Failure Loss Estimates").*

For the other eleven (11) hazards, CHR developed an Average Annual Loss number for every county within the Commonwealth. This was developed in order for each county to have a general understanding of the potential effects for each hazard posed in terms of average dollar loss per year. As mentioned above, this data model was developed using the best available data for each hazard. SHELDUS data was used for Flood, Earthquake, Forest Fire, Drought, Hail Storm, Severe Storm, Severe Winter Storm, and Tornado's. While SHELDUS is the best available data source for many events, it does at times provide a simplified view of events within a state, taking the total losses from the event and dividing the losses evenly among the affected counties. This is done due to shortcomings in the source data that SHELDUS uses and while each affected county does not necessarily have equal losses as you may see in the table, a more refined breakdown of losses for all events is currently not available due to the data capture limitations of SHELDUS.

For the assessed hazards not listed above, alternative data sources were used due to the availability of Kentucky specific data and/or the lack of SHELDUS data, the breakdown of those sources and hazards follows. Data from the Kentucky Division of Abandoned Mine Lands (AML) was used for Mine/Land Subsidence. This particular data provided a specific loss location that has been tracked by AML. Again, this data is the best available data for this specific hazard at this moment. Kentucky Geological Survey (KGS) data was used for Landslide data capture. KGS, a long-standing partner with KYEM and CHR have recently began to track specific incident data through a created GIS database. For Extreme Temperature CHR used both SHELDUS and NCDC data in order to capture extreme cold events, which were only present in the NCDC data records.

In order to capture potential losses for each hazard CHR and KYEM scoured the best available data sources. Again, this data will be enhanced with the SIE data capture within CHAMPS for future iterations. This potential loss data can be found in ***Appendix 3-2*** "Hazard Average Annualized Loss"

State Facilities: Hazard Boundary Overlay Loss Estimation Model

The vulnerability assessment and potential loss estimate for state-owned facilities were determined using the same methodology. The Division of State Risk and Insurance which insures state-owned facilities provided CHR with an updated list of state-owned facilities and the total insurance coverage on each structure. The database contained 6,881 state-owned, addressed facilities.

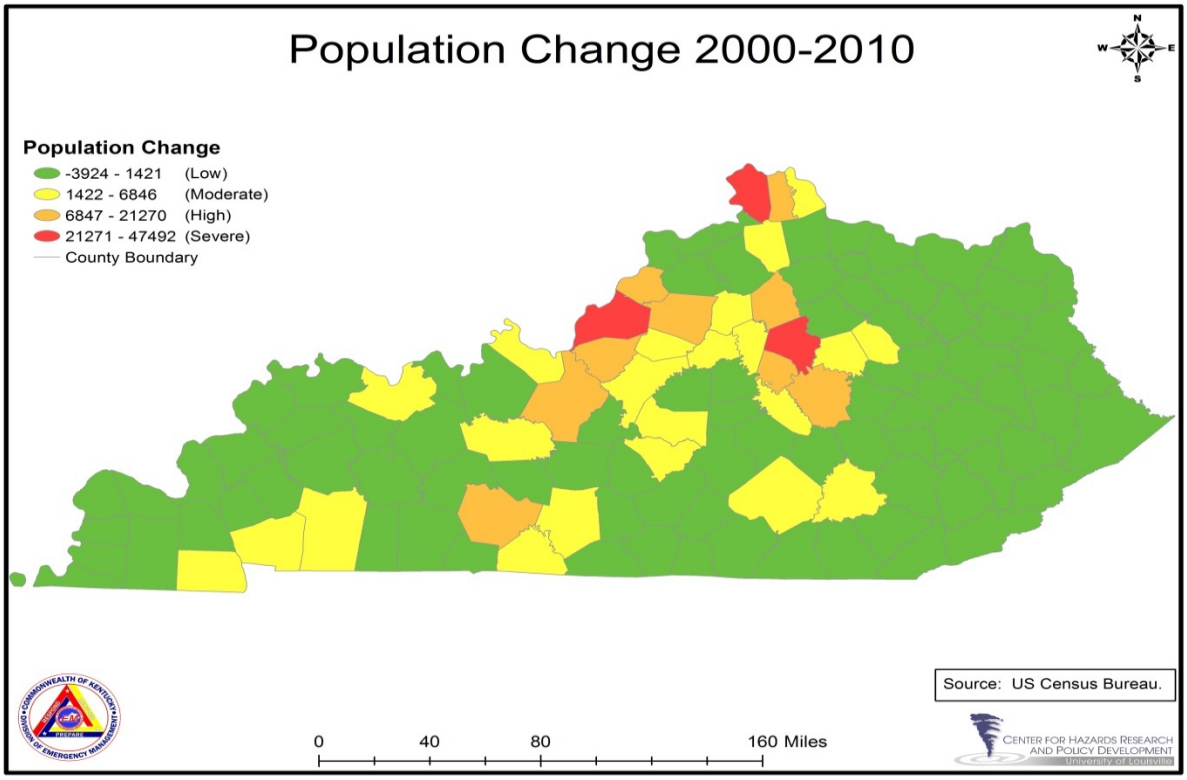
To work with the addressed state-owned facilities, each had to be geo-coded in a GIS system. Geo-coding is a GIS process where an address is assigned a geographic location according to addressed road coverage. This method gives the address from the database an x, y coordinate position in the world. The CHR team performed this geo-coding process using ArcGIS Street map. This data was geo-coded and then double checked for accuracy for the 2013 plan.

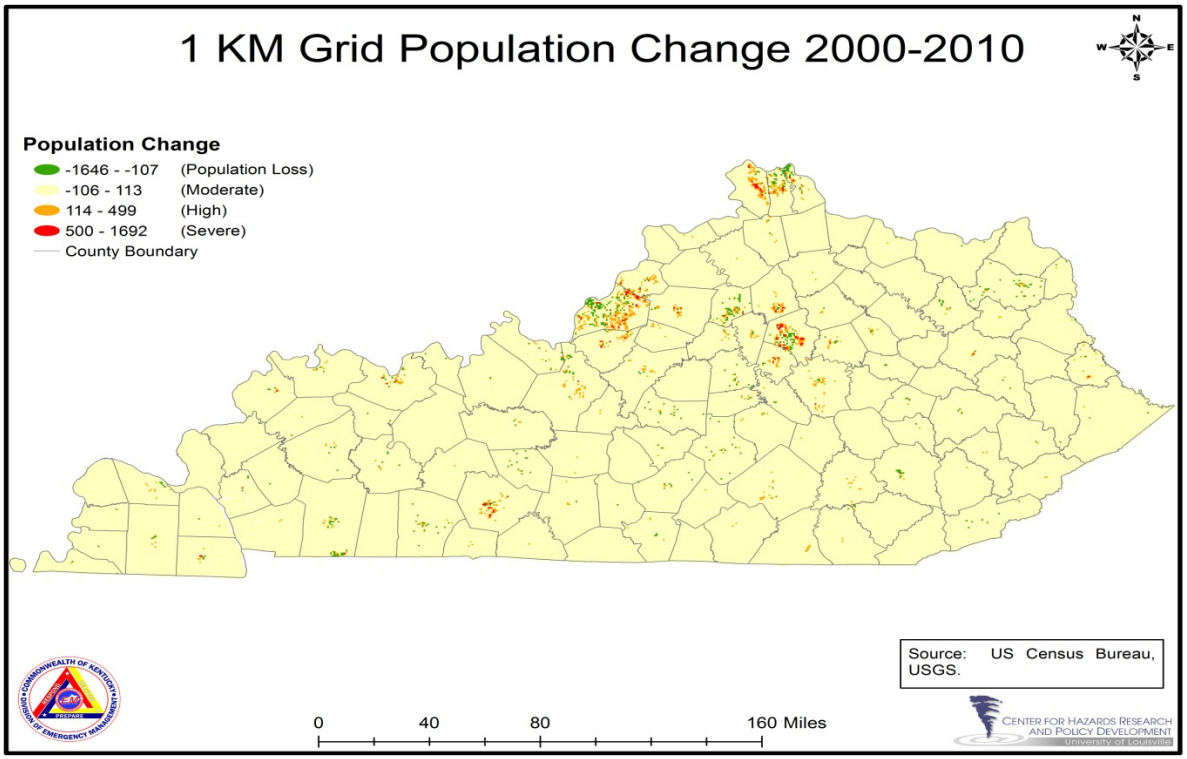
Using the "Severe Hazard Score" hazard boundary layer from the Hazard Score grid, vulnerability assessments and loss estimates were performed on the state facilities. The Severe Hazard Score 1 KM MGRS grids were used as the hazard boundary that was used to overlay on the geo-referenced state facility GIS file. The state facilities that were located within the severe hazard zones were then identified and assumed to be vulnerable and estimated to be damaged during an event. To identify State Facilities that are vulnerable per county throughout the Commonwealth, CHR created a table that displays the total number of facilities and the potential losses to those facilities identified within a "Severe" hazard area (1 KM grid Hazard Score) (See ***Appendix 3-4*** "Hazard Facility Vulnerability and Loss Estimations"). These estimates should be used to assess State Facilities' vulnerability and potential loss from hazard events. In addition to the County Summary data, Hazard Facility Vulnerability and Loss Estimations By Building Type tables are included in Appendix 3-4. Appendix 3-4 is designed to show a county level loss estimation by the type of state owned facility. Each state facility was broken into its appropriate Building Class/Type. The following is the listing and definition of the Division of State Risk and Insurance Building Types.

Building Type	Definition
RESIDENCE	A facility used as living quarters.
STORAGE	A facility used to store objects or goods.
PUBLIC SAFETY	A facility devoted to law enforcement or other public safety activities.
RECREATION & SPORT	A facility devoted to recreation or sport activities such as parks, game lands, etc.
FOOD SERVICE	A facility devoted to the preparation and service of food.
OFFICE	A facility devoted to any kind of administrative or office functions.
FARMING	A facility concerned with the raising of crops, plants or animals.
EXHIBITION	A facility devoted to the presentation of indoor and outdoor exhibits and shows.
MEDICAL	A facility devoted to delivering public health services such as medical, psychiatric treatment, nursing or other health care.
CORRECTIONS	A facility concerned with the imprisonment and treatment of public offenders.
GENERAL MAINTENANCE	A facility devoted to general repair, clean-up or maintenance of Commonwealth property.
TRAVEL	A facility devoted to travel activities such as an airport.
PARKING	A facility devoted to the parking of motor vehicles.
VEHICLE MAINTENANCE	A facility devoted to the maintenance or repair of Commonwealth motor vehicles.
HANGAR	A facility used for storage of airplanes.
EDUCATION	A facility devoted to instruction, educational and teaching activities.
MECHANICAL	A facility providing electricity, gas, water, etc. for power, heat and other services.
DEFENSE	A facility concerned with the various functions of the Department of Military Affairs.
RESEARCH	A facility devoted to research, experimentation or analysis.
MANUFACTURING	A facility devoted to the assembly or manufacture of objects.

Changes in Development

An important step in developing solid mitigation policy that influences changes in potential loss from hazard events is to identify areas that are displaying substantial growth. Areas with high growth are increasing their exposure to hazards and these changes will increase the risk to future hazard events. The state hazard mitigation plan and local hazard mitigation plans should be used to identify high-risk areas to each hazard and evaluate the development patterns within the high hazard zones to ensure that any development is done in a way that minimizes risk. To identify these particular high growth areas, CHR decided to identify counties and 1KM grids with significant growth. Using 2010 and 2000 Census data (which is the best available data to show population trends at this time), CHR developed maps which depict areas showing high development based on population change from 2000-2010. Furthermore, the grid level population changeassessment was completed using the most current development data. It used 2010 Census population data, 2012 ACS property value data, and 2012 ESRI business data to ensure the most up-to-date picture of Kentucky was given.


Population Change 2000-2010
Population Change
-3924 - 1421 (Low)
1422 - 6846 (Moderate)
6847 - 21270 (High)
21271 - 47492 (Severe)
County Boundary
Source: US Census Bureau.
0 40 80 160 Miles
CENTER FOR HAZARDS RESEARCH AND POLICY DEVELOPMENT
University of Louisville


1 KM Grid Population Change 2000-2010
Population Change
-1646 - -107 (Population Loss)
-106 - 113 (Moderate)
114 - 499 (High)
500 - 1692 (Severe)
County Boundary
Source: US Census Bureau, USGS.
0 40 80 160 Miles
CENTER FOR HAZARDS RESEARCH AND POLICY DEVELOPMENT
University of Louisville

Hazard Category: FLOOD

Flood

Identifying Hazards: Flood

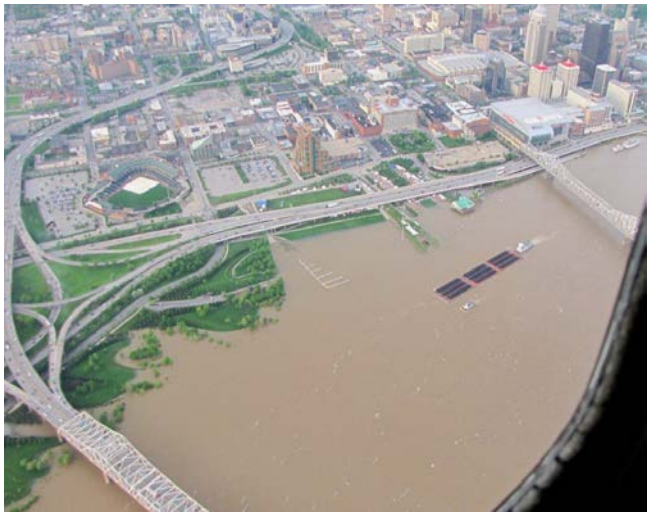
Description

As defined by USGS, flooding is *a relatively high stream flow that overflows the natural or artificial banks of a stream or that submerges land not normally below water level*, and, as a natural event, is caused in a variety of ways. Winter or spring rains, coupled with melting snows, can fill river basins too quickly. Torrential rains from decaying hurricanes or other tropical systems can also produce flooding. The excess water from snowmelt, rainfall, or storm surge accumulates and overflows onto lowlands, adjacent to rivers, lakes, and oceans which are subject to recurring floods; most commonly referred to as floodplains. Currently, floodplains in the U.S. encompass over nine (9) million households.

Factors determining the severity of floods include:

- Rainfall intensity and duration
  - A large amount of rain over a short time can result in flash flooding.
  - Small amounts may cause flooding where the soil is already saturated.
  - Small amounts may cause flooding if concentrated in an area of impermeable surfaces.
- Topography and ground cover
  - Water runoff is greater in areas with steep slopes and little vegetation.

Frequency of inundation depends on the climate, soil, and channel slope. In regions without extended periods of below-freezing temperatures, floods usually occur in the season of highest precipitation.



Kentucky Flooding 2011

Types

There are a multitude of reasons that floods may occur, with each type of flooding having a variety of environmental effects post-flood, and are generally grouped into seven (7) types; regional, river or riverine, flash, ice-jam, storm surge, dam and levee failure, and debris, landslide, and mudflow flooding.

1. *Regional Flooding* can occur seasonally when winter or spring rains, coupled with melting snow, fill river basins with too much water too quickly. The ground may be frozen, reducing infiltration into the soil and thereby increasing runoff. Extended wet periods during any part of the year can create saturated soil conditions, after which any additional rain runs off into streams and rivers, until river capacities are exceeded. Regional floods are many times associated with slow-moving, low-pressure or frontal storm systems including decaying hurricanes or tropical storms.

2. *River or Riverine Flooding* is a high flow or overflow of water from a river or similar body of water, occurring over a period of time too long to be considered a flash flood.

3. *Flash Floods* are quick-rising floods that usually occur as the result of heavy rains over a short period of time, often only several hours or even less. Flash floods can occur within several seconds to several hours and with little warning. They can be deadly due to the rapid rises in water levels and devastating flow velocities produced.

4. *Ice-Jam Flooding* occurs on rivers that are totally or partially frozen. A rise in stream stage will break up a totally frozen river and create ice flows that can pile up on channel obstructions such as shallow riffles, log jams, or bridge piers. The jammed ice creates a dam across the channel over which the water and ice mixture continues to flow, allowing for more jamming to occur. Backwater upstream from the ice dam can rise rapidly and overflow the channel banks. Flooding moves downstream when the ice dam fails, and the water stored behind the dam is released. At this time the flood takes on the characteristics of a flash flood, with the added danger of ice flows that, when driven by the energy of the flood-wave, can inflict serious damage on structures. An added danger of being caught in an ice-jam flood is hypothermia, which can quickly kill.

5. *Storm-surge flooding* is water which is pushed up onto otherwise dry land by onshore winds. Friction between the water and the moving air creates drag which, depending upon the distance of water (fetch) and the velocity of the wind, can pile water up to depths greater than 20 feet. Intense, low-pressure systems and hurricanes can create storm-surge flooding. The storm surge is unquestionably the most dangerous part of a hurricane as pounding waves create very hazardous flood currents.

6. *Dam-and Levee-Failure Flooding* are potentially the worst flood events. A dam failure is usually the result of neglect, poor design, or structural damage caused by a major event such as an earthquake. When a dam fails, an excess amount of water is suddenly released downstream, destroying anything in its path. Dams and levees are built for flood protection. They usually are engineered to withstand a flood with computed risk of occurrence. For example, a dam or levee may be designed to contain a flood at a location on a stream that has a certain probability of occurring in any one year. If a larger flood occurs, then that structure will be overtopped. If during the overtopping the dam or levee fails or is washed out, the water behind it is released and becomes a flash flood. Failed dams or levees can create floods that are catastrophic to life and property because of the tremendous energy of the released water.

7. *Debris, Landslide, and Mudflow Flooding* is created by the accumulation of debris, mud, rocks, and logs in a channel, forming a temporary dam. Flooding occurs upstream as water becomes stored behind the temporary dam and then becomes a flash flood when the dam is breached and rapidly washes away. Landslides can create large waves on lakes or embankments and can be deadly. Mudflow floods can occur when volcanic activity rapidly melts mountain snow and glaciers, and the water mixed with mud and debris moves rapidly down slope.

Facts

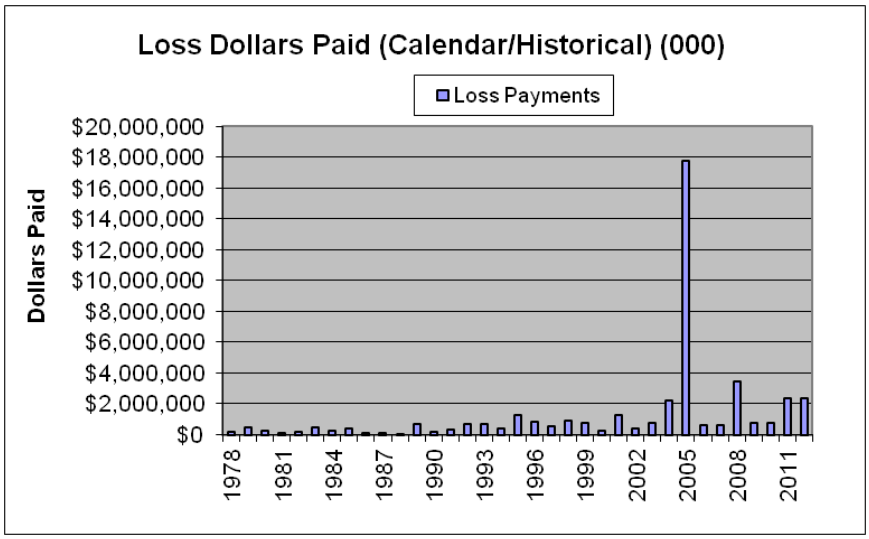
- Floods caused by Hurricane Katrina resulted in over $200 billion in losses, resulting in the most costly natural disaster in U.S. history.
- Annually, average losses from 30-year floods in the U.S. are over $8 billion in damages and 95 deaths.
- Flooding is the most common natural disaster in the United States.
- More than 2,200 lives were lost in the Johnstown, Pennsylvania flood of 1889, a flood that was caused by a dam failure.
- Most flood-related deaths are due to flash floods.
- 50% of all flash-flood fatalities are vehicle related.
- 90% of those who die in hurricanes drown in flood waters.

Impacts

Though fatalities associated with all types of flooding have steadily declined in the U.S. over the last half century, the average annual death toll is still over 200. Advanced warning systems are now commonplace and give residents time to plan, but an increase in urban and coastal development has caused the monetary losses associated with flooding to increase drastically.
Most homeowners' insurance policies do not cover floodwater damage, so homeowners without flood insurance are at a high risk for loss. Since 1978, over $47 billion in flood

loss payments have been made nationwide by the National Flood Insurance Program. 2005, had by far the most loss dollars paid (almost $18 billion), as a result of Hurricane Katrina. The next largest yearly paid loss dollars amount was in 2008 at almost $3.5 billion, largely as a result of Hurricane Ike. New Jersey had the highest total flood loss payments in 2011 in the United States, followed by New York, Pennsylvania, North Carolina, North Dakota, Connecticut, Vermont, Mississippi, Missouri and Louisiana.

Hurricane Sandy is the most recent example of the devastation flooding can cause in urban areas. In October 2012, Hurricane Snadyhit the coast of New York and New Jersey, affecting the largest and one of the most densely populated cities in the United States, New York City. Over 63,500 flood insurance claims were paid, second only to Hurricane Katrina, for a total of $2,649,099,182. The event also resulted in over 100 deaths, most of who drowned in the storm surge.



Source: FEMA, http://www.fema.gov/policy-claim-statistics-flood-insurance/policy-claim-statistics-flood-insurance/policy-claim-13/loss

According to the NWS, water year 2011 was a year of record-breaking, prolonged floods along some of the nation's largest rivers, the Missouri, Ohio and Mississippi. Direct flood damages during this water year totaled $8.41 billion. Over 100 people died as a result of this flooding, over half of which were attributed to flash flood events. These flood events were largely due to spring snowmelt flooding that resulted from heavy precipitation the preceding fall and summer.

Profiling Hazards: Flood

FLOOD PROFILE RISK TABLE	
Period of occurrence:	For river flooding - January through May For flash flooding - Anytime, but primarily during summer rains
Number of events: (1960-2013)	5,934*
Annual Rate of Occurrence:	112
Warning time:	River flooding - 3-5 days Flash flooding - minutes to several hours Out-of-bank flooding - several hours/days
Potential impacts:	Impacts human life, health, and public safety. Utility damages and outages, infrastructure damage (transportation and communication systems), structural damage, fire, damaged or destroyed critical facilities, and hazardous material releases. Can lead to economic losses such as unemployment, decreased land values, and agribusiness losses. Floodwaters are a public safety issue due to contaminants and pollutants.
Recorded losses:	$2,301,445,697*
Annualized Loss:	$43,423,504
Extent (Historical)[1]:	Date: March 1997 Damage: $400 M Location: 100 counties/statewide

*Data captured from SHELDUS 10.1 (occurrence data captures county-level events across the state)

Flooding, which is one of the most significant natural hazards in Kentucky, occurs within the state every year, with several substantial floods occurring annually. Since 2010, four (4) Presidential disaster declarations have been made for the Commonwealth of Kentucky, all of which have included flooding. Kentucky's topography contains 13 major drainage basins to accommodate 40-50 inches of average rainfall (maximum during winter and spring, minimum during late summer and fall), The state contains 89,431 miles of rivers and streams, 637,000 acres of wetlands, 18 reservoirs over 1,000 acres in size, and 228,382 acres of publicly-owned lakes and reservoirs.

It is no surprise, given the above statistics, approximately 300 communities statewide have identified flood-prone areas; and for many of the communities the economic, social, and physical damage caused by flooding can be severe. SHELDUS data indicates there have been 670 deaths and 154 injuries since 1960 due to flooding. And, flood loss payments totaling $283,207,948 have been made to Kentuckians since 1978. According to NOAA NCDC data, from 2010 to 2012 there were 94 days with a flood event affecting 102 out of the 120 counties in Kentucky. These flood events resulted in

[1] See below descriptions/historical accounts for further examples that serve as "extent," i.e. these are all accounts by which one can compare how bad flooding can become in the Commonwealth of Kentucky.

one (1) death, four (4) injuries, and $62 million worth of combined property and crop damages.

The following is a list of flood-related Presidential Declarations in Kentucky from 1970 to the present. Because only major disasters are included, a number of isolated, smaller events are not listed.

Kentucky Presidential Flood Disaster Declarations		
Disaster Number	Declaration Date	Counties Affected
282	February 2, 1970	12
288	June 5, 1970	13
332	May 15, 1972	10
461	March 29, 1975	17
529	April 6, 1977	15
568	December 12, 1978	37
705	May 15, 1984	28
821	February 24, 1989	67
834	June 30, 1989	12
846	October 30, 1989	11
893	January 29, 1991	19
1163	March 3, 1997	101
1388	August 15, 2001	20
1407	April 4, 2002	37
1414	May 7, 2002	29
1471	June3, 2003	44
1475	July 2, 2003	23
1523	June 6, 2004	77
1537	August 6, 2004	27
1703	May 25, 2007	9
1746	February 21, 2008	23
1757	May 19, 2008	15
1818	February 5, 2009	102
1841	May 29, 2009	24
1855	August 14, 2009	2
1912	May 11, 2010	83
1925	July 23, 2010	7
4008	July 25, 2011	7
4057	March 6, 2012	23

Source: Kentucky Division of Emergency Management,
FEMA www.fema.gov/disaster

Flood-related **Presidential Disaster Declarations 2005-2013**																		
Disaster Declaration	Incident Period	Individual Assistance Applications*	Amount Disbursed*	Total Public Assistance Grants**	Dam Failure	Drought	Earthquake	Extreme Temp.	Flood	Hailstorm	Karst/Sinkhole	Land/Mine	Landslide	Severe Storm	Severe Winter	Tornado	Forest Fire
DR-4057	February 29- March 3, 2012	5,746	$ 10,378,250	$ 12,438,032					x					x		x	
DR-4008	June 19 - 23, 2011	820	$ 2,886,169	$ 2,428,630					x					x		x	
DR-1976	April 12- May 20, 2011	2,330	$ 9,239,830	$ 31,886,410					x					x		x	
DR-1925	July 17-30, 2010	2,548	$ 10,602,929	$ 6,372,211					x				x	x			
DR-1912	May 1, 2010	7,343	$ 20,784,629	$ 22,522,805					x				x	x			
DR-1841	May 3-20, 2009	5,543	$ 15,117,446	$ 34,825,014					x				x	x		x	
DR-1818	January 26 - February 13, 2009	not requested	not requested	$213,768,779					x						x		
DR-1855	August 4, 2008	12,406	$ 17,701,502	$ 3,791,750					x					x			
DR-1757	April 3-4, 2008	not requested	not requested	$ 3,499,938					x				x	x		x	
DR-1746	February 5-6, 2008	1,032	$ 1,466,605	$ 4,954,738					x					x		x	

*Source: KY Division of Emergency Management, Recovery Branch. IA Disaster Summary by County.
**Source: FEMA.gov

A number of significant flooding incidences occurred in late 19th and early 20th centuries within the state, including an event in February 1884, lasting almost two (2) weeks. On February 14, 1884, the Ohio River crested at 48 feet in Louisville; 24 feet above the base flood stage. Towns as far away as Paducah were also inundated for long periods of time.

In January of 1913, unseasonably high amounts of rain in Kentucky, Indiana, and Ohio caused almost every major river and stream in the state to flood, leading to what U.S. Weather Bureau officials referred to as “vast inland seas”. In the Louisville area alone, property damages were estimated at over $200,000 and crop losses totaling over $50,000.

The flood of 1937, is one of the most devastating floods in Kentucky history. In the month of January the state incurred four (4) times the normal amount of precipitation. With the river cresting at over 57 feet in Louisville, 75% percent of the city was underwater and over 175,000 residents were evacuated. Further downstream in Paducah, where the river crested at over 60 feet, residents were evacuated as well. The damages incurred by the entire state were estimated at $250 million, an extremely large sum for the economic climate of the 1930s.

On March 1, 1997, Louisville set a record for the highest amount of precipitation to fall in a single day at 10.48 inches. That March was also the wettest March on record for Louisville, with 17.52 inches of rain for the month. This was part of more widespread rain in central Kentucky and the surrounding areas that led to massive flooding of the Ohio River unlike any in many decades. The crest of the river reached 70.47 feet in Louisville, causing about $200 million in damages with 50,000 homes affected and the

closing of Interstates 64 and 65. Ninety-two counties in Kentucky were declared disaster areas with approximately $400 million in damages, tens of thousands of people evacuated from their homes, and seven deaths occurred. Record flood stages were reached at numerous streams throughout the state.

In August 2009, a record high rainfall for a single day in August occurred in the Louisville area; a record unbroken since 1879. During this event 4.53 inches of rain fell at Louisville International Airport, with 3 inches falling within one hour. The Louisville Free Public library sustained $1 million dollars in damages and the University of Louisville alone sustained upward of $20 million in damages.

Beginning on Derby Day May 1, 2010, the entire state was inundated with a torrential rain event. A similar deluge in Tennessee impacted rivers flowing into Kentucky. In all, 84 Kentucky counties were impacted by this event and a Presidential declaration was issued on May 11, 2010. Three (3) weeks after the storm, the far western areas of the Commonwealth were still submerged. FEMA resources were deployed to implement both the Public Assistance Program and the Individuals and Households Assistance Program. Estimated Public Assistance projects exceed $60 million.

The Commonwealth has identified numerous Severe Repetitive Loss (SRL) and Repetitive Loss (RL) properties which both KYEM and KDOW considered to be of high priority for mitigation measures. See ***Appendix 3-5*** for RL/SRL by county.

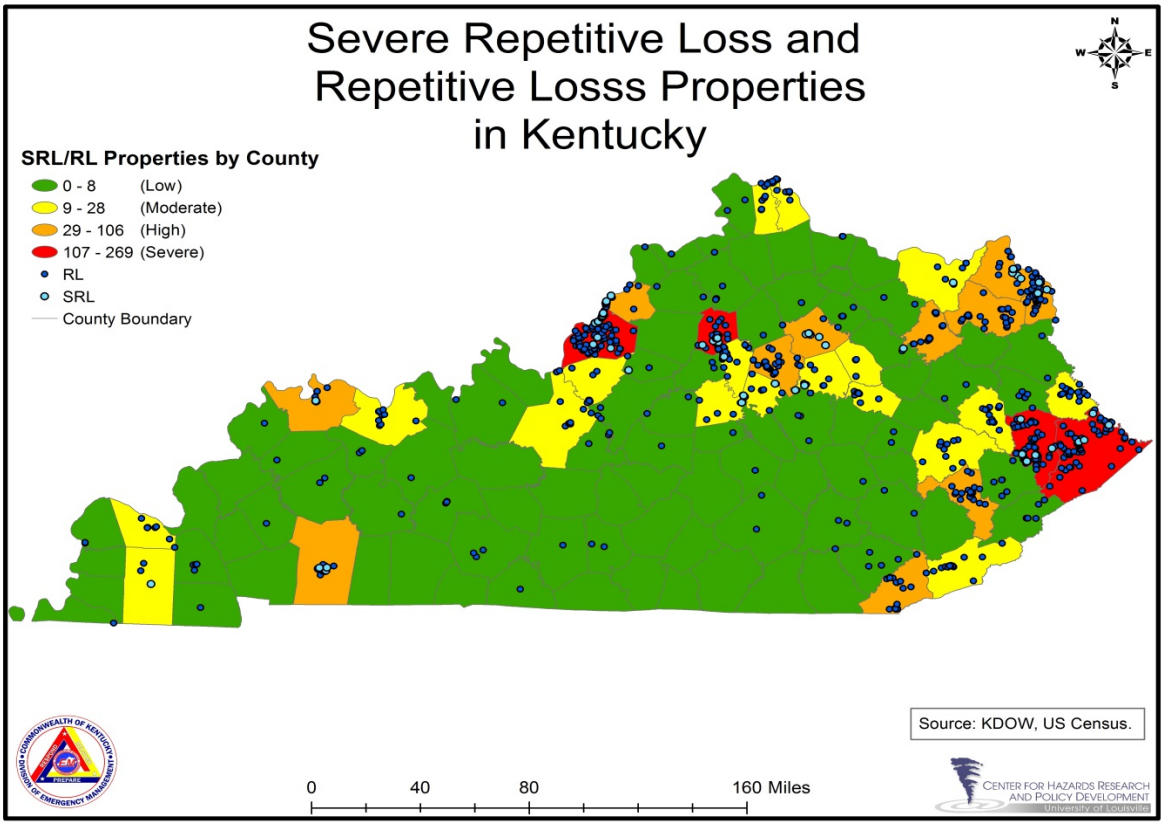
REQUIREMENT
§201.4 (C) (3) (V):

The Commonwealth of Kentucky may request the reduced cost share authorized under 79.4 (c) (2) of this chapter for the FMA and SRL programs. If it has an approved Mitigation Plan…that also identifies specific actions the Commonwealth of Kentucky has taken to reduce the number of repetitive loss properties (which must include severe repetitive loss properties), and specifies how the Commonwealth of Kentucky intends to reduce the number of such repetitive loss properties.

BEGINNING HERE

C. Addressing Repetitive Loss Properties in the Commonwealth of Kentucky's Risk Assessment

Western Kentucky Flooding 2011



Assessing Vulnerability by Jurisdiction: Flood

<u>Grid-Level Risk Assessment Model</u>

Flood Vulnerability Score = Exposure Score + Hazard Score

Assessing Kentucky's vulnerability to flood was determined through first calculating the Flood Hazard Score. The Flood Hazard Score was calculated by studying three (3) sources of data. Each of the datasets was provided by the Kentucky Division of Water (KDOW) and FEMA. The first data layer used to create the Flood Hazard Score was the Digital Flood Insurance Rate Map (DFIRM). The DFIRM displays a geo-referenced data layer that depicts where flooding could occur. To analyze Kentucky's risk to flood according to the DFIRM data, the DFIRM layer was overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based on the percent of the area the DFIRM covered within each grid. This percentage of area affected by the mapped flood potential area (DFIRM) was then calculated and scored 0-1 to develop 50% of the Flood Hazard Score.

The next step determined the total number of Severe Repetitive Loss (SRL) and Repetitive Loss (RL) properties within each 1 KM MGRS grid. This data displayed where concentrations of flood events have occurred, thus producing areas of risk. Once all the SRL and RL property points were aggregated to their appropriate grid, each grid was giving a score 0-1 to create the other 50% of the Flood Hazard Score.

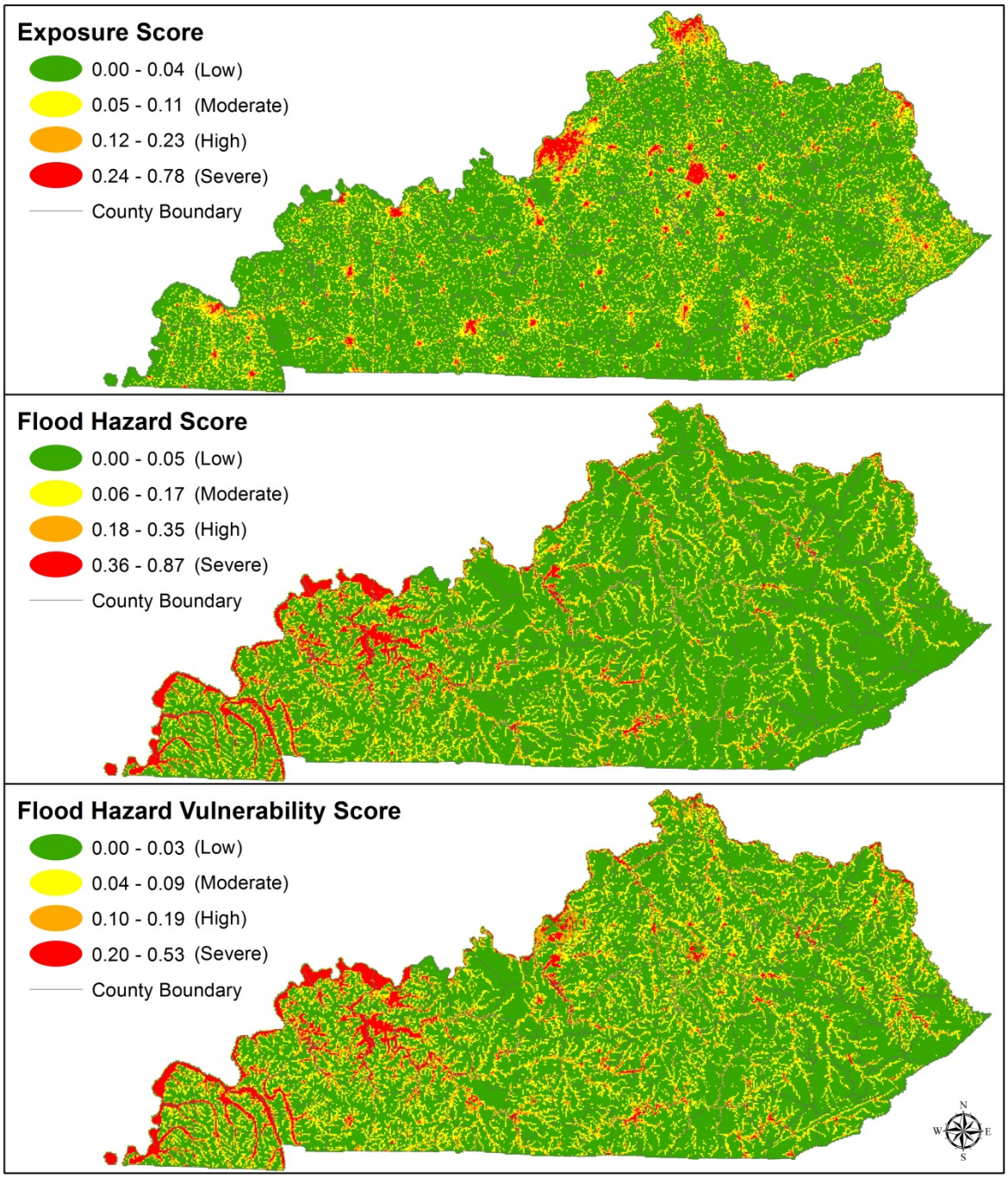
The Flood Hazard Score was then calculated by adding the two (2) scores together and scored 0-1. It is important to note if the Flood Hazard Score inputs equaled 0, then the Flood Hazard Vulnerability Score equaled 0.

Finally, the Flood Vulnerability Score was calculated for each 1 KM MGRS grid by adding each grid's Exposure Score by its Flood Hazard Score and then scored 0-1. Once the final Flood Vulnerability Scores were calculated the composite scores were broken into four (4) categories, using the Natural Breaks classification system (1. Low, 2. Moderate, 3. High, 4. Severe) which demonstrates different levels of vulnerability displayed on the map.

The Grid-Level Risk Assessment Model should be used to identify specific areas of vulnerability located throughout Kentucky. This model provides 106,178 equal areas of comparison for the end users to assess hazard vulnerability. The best way to view and use this data is through a GIS viewer.

Western Kentucky Flooding 2011

The following map displays the maps and components of the Flood Vulnerability Score.



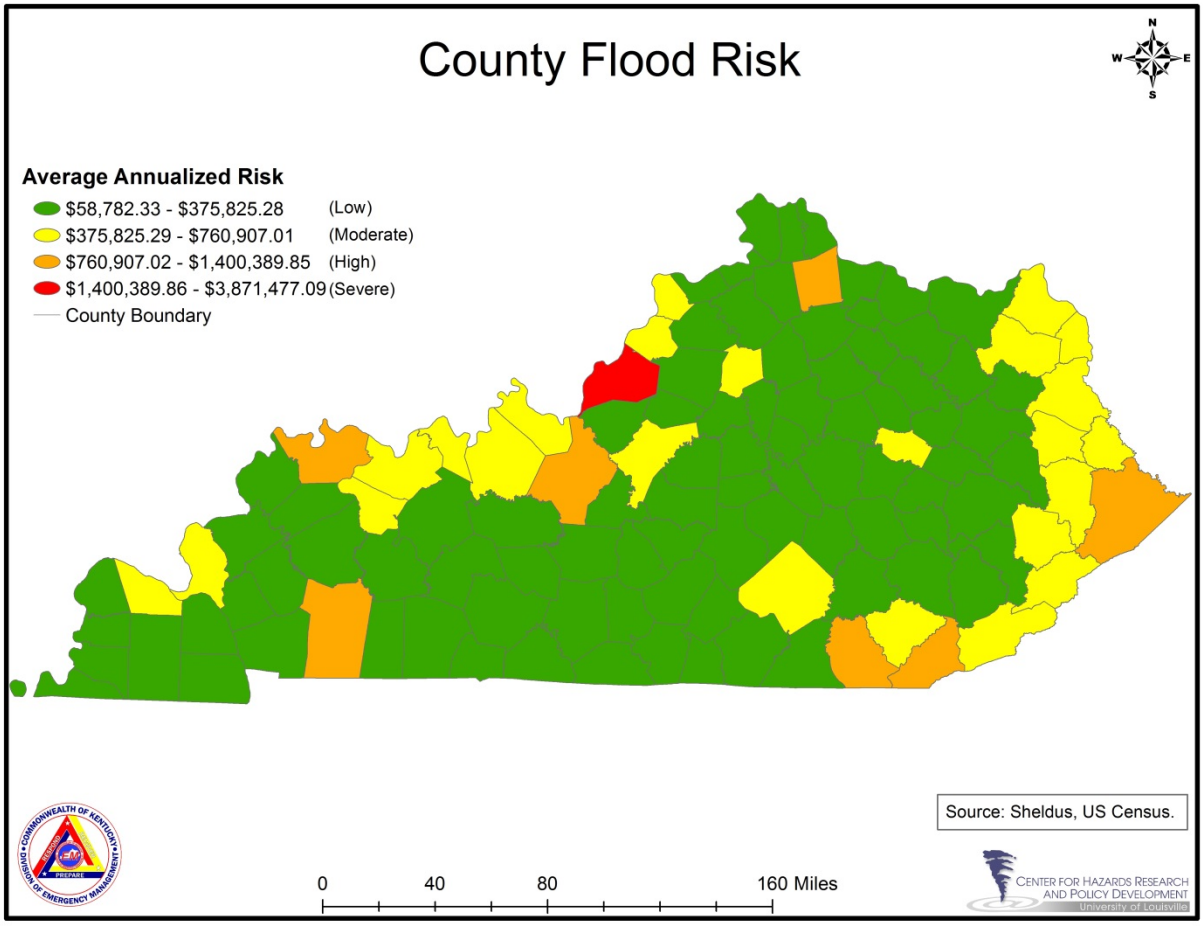
Source: Exposure- Division of State Risk and Insurance, ESRI, Kentucky Infrastructure Authority, Kentucky Office of Geographic Information, Kentucky Transportation Cabinet, KYEM, Public Service Commission, and the US Census Bureau. Hazard: FEMA, Kentucky Division of Water.

0 30 60 120 Miles

CENTER FOR HAZARDS RESEARCH AND POLICY DEVELOPMENT
University of Louisville

County-Level Risk Assessment Model

The Flood County Risk Assessment Model was created using the Flood Average Annual Loss data for each county. The average annual loss is calculated by multiplying each county's annual rate of occurrence by their average losses (See ***Appendix 3-2*** "Hazard Average Annualized Loss"). This data was then joined to a county map for display as seen below.



The County-Level Risk Assessment Model should be used to compare county-level risk. This data depicts which counties are experiencing the most occurrences and losses from flooding comparatively across Kentucky.

Hazard Category: GEOLOGIC/EARTHQUAKE

Earthquake

Identifying Hazards: Earthquake

Description

According to the U.S. Geological Survey, an earthquake is *a shaking of the ground caused by the sudden release of accumulated strain by an abrupt shift of rock along a fracture in the Earth or by volcanic or magmatic activity, or other sudden stress changes in the Earth*. For hundreds of millions of years, the forces of plate tectonics - massive, irregularly-shaped slabs of rock - have shaped the Earth as these huge plates that form the Earth's surface move slowly over time.

When a substantial amount of energy has accumulated during these tectonic interactions, the plates move in a way which releases stored energy and produce the seismic waves which generate earthquakes. The areas of greatest tectonic instability occur at the perimeters of the slowly moving plates, as these locations are subjected to the greatest strains from plates traveling in opposite directions and at different speeds. However, some earthquakes do occur in the middle of plates for various reasons.

The movement of the earth‘s surface during earthquakes (or explosions) is the catalyst for most of the damage during an earthquake. Produced by waves generated by a sudden slip on a fault or sudden pressure at the explosive source, ground motion travels both through the earth and along its surface, amplified by soft soils overlying hard bedrock; a phenomenon referred to as ground motion amplification. Ground motion amplification can cause a great deal of damage during an earthquake, even to sites very far from the epicenter; the epicenter being the point on the Earth’s surface that is directly above the area where rock has broken on the tectonic plate below. Earthquakes strike suddenly and without warning and can occur at any time of the year, any time of the day or night. Worldwide, 70 to 75 damaging earthquakes occur annually.

The Northridge (Los Angeles), California, earthquake of January 17, 1994, struck a modern urban environment generally designed to withstand the forces of earthquakes. Its economic cost, nevertheless, has been estimated at over $30 billion. Exactly one (1) year later, Kobe, Japan, a densely populated community less prepared for earthquakes than Northridge, was devastated by the most costly earthquake ever to occur. Property losses were projected at over $100 billion, and at least 5,530 people were killed. These two (2) earthquakes tested building codes and construction practices, as well as emergency preparedness and response procedures.

One of the most destructive earthquakes to date occurred in Haiti in 2010, which resulted in 316,000 deaths, hundreds of thousands of injuries, and millions of people displaced from their homes. The disaster also led to a widespread cholera epidemic and untold economic damages.

Over 75 million Americans in 39 states face a significant risk of experiencing the effects of a substantial earthquake. California experiences the greatest amount of damaging earthquakes in terms of effected infrastructure and damage to private property. However, Alaska experiences the greatest actual number of large earthquakes, most of which occur in uninhabited areas of the state. The largest earthquake felt in the contiguous United States was along a 600 mile stretch of the Cascadia Subduction Zone between Vancouver, British Columbia and Northern California in the year 1700, where the oceanic Juan de Fuca plate is sliding beneath the North American plate. The earthquake leveled entire villages, collapsed structures in many others, and caused landslides, tsunamis, and devastating swells down much of the Northwest coast of North America. A tsunami produced by this earthquake travelled across the Pacific Ocean, also causing significant levels of devastation on coastal areas of Japan.

Types

Plate boundaries are characterized into four (4) distinct types:

1) Divergent boundaries – a new crust is created as two plates move away from another
2) Convergent boundaries – areas where tow plates are coming together and thus losing crust as one plate slides under another
3) Transform boundaries –two plates slide horizontally past one another without creating or destroying boundaries
4) Plate boundary zones – broad belts without well defined boundaries or plate interaction

Earthquakes are measured in terms of magnitude and intensity using the Richter Scale and Modified Mercalli Scale of Earthquake Intensity.

The Richter magnitude scale measures an earthquake‘s magnitude using an open-ended logarithmic scale that describes the energy release of an earthquake through a measure of shock wave amplitude. The earthquake‘s magnitude is expressed in whole numbers and decimal fractions. Each whole number increase in magnitude represents a 10-fold increase in measured wave amplitude, or a release of 32 times more energy than the preceding whole number value.

The Modified Mercalli Scale measures the effect of an earthquake on the Earth‘s surface. Composed of 12 increasing levels of intensity that range from unnoticeable shaking to catastrophic destruction, the scale is designated by Roman numerals.

There is no mathematical basis to the scale; rather, it is an arbitrary ranking based on observed events. The lower values of the scale detail the manner in which the earthquake is felt by people, while the increasing values are based on observed structural damage. The intensity values are assigned after gathering responses to questionnaires administered to postmasters in affected areas in the aftermath of the earthquake.

Modified Mercalli Intensity Scale with Corresponding Richter Scale				
Intensity	Verbal Description	Witness Observations	Maximum Acceleration (cm/sec^2)	Corresponding Richter Scale
I	Instrumental	Detectable on seismographs	<1	<3.5
II	Feeble	Felt by some people	<2.5	3.5
III	Slight	Felt by people resting	<5	4.2
IV	Moderate	Felt by people walking	<10	4.5
V	Slightly Strong	Sleepers awake; church bells ring	<25	<4.8
VI	Strong	Trees sway; suspended objects swing; objects fall off shelves	<50	5.4
VII	Very Strong	Mild alarm; walls crack; plaster falls	<100	6.1
VIII	Destructive	Moving cars uncontrollable; masonry fractures; poorly constructed buildings damaged	<250	
IX	Ruinous	Some houses collapse; ground cracks; pipes break open	<500	6.9
X	Disastrous	Ground cracks profusely; many buildings destroyed; liquefaction and landslides widespread	<750	7.3
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

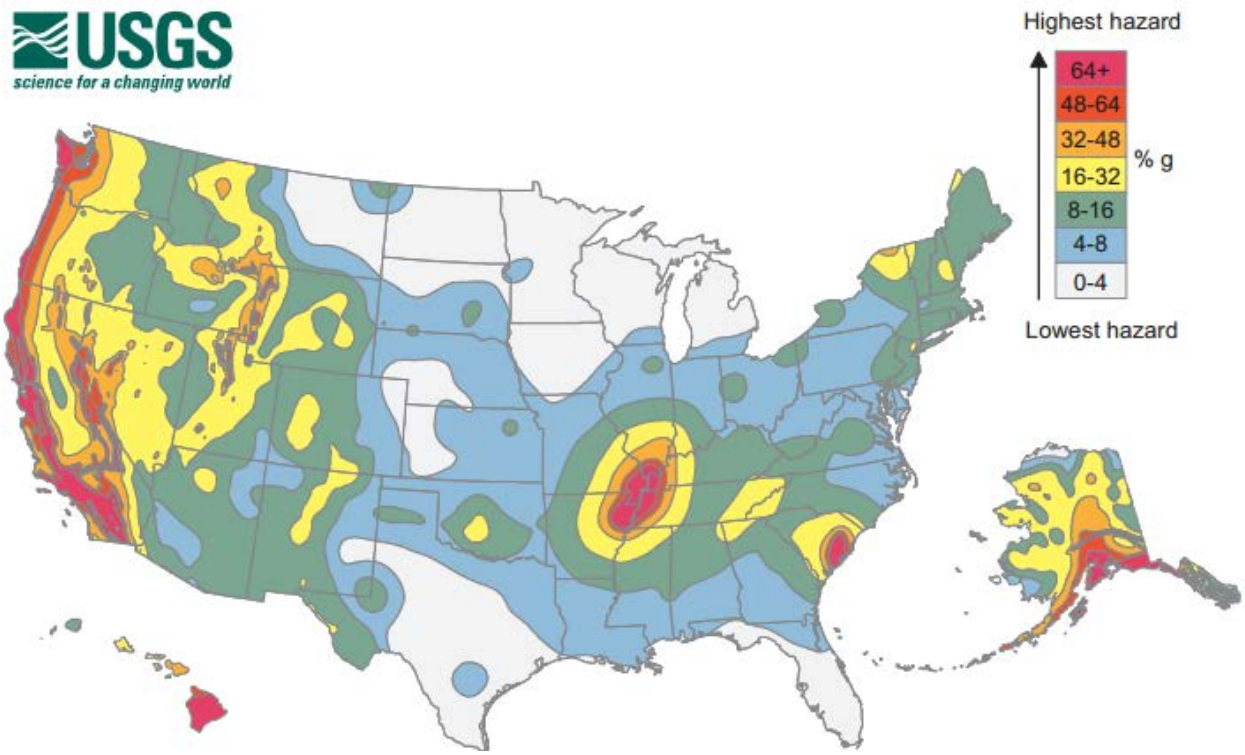
Source: US Geological Survey

10 Largest Earthquakes in the Contiguous United States		
Richter Scale Magnitude	Date	Location
~9.0	January 26, 1700	Cascadia Subduction Zone
7.9	January 9, 1857	Fort Tejon, CA
7.8	April 18, 1906	San Francisco, CA
7.8	February 24, 1892	Imperial Valley, CA
7.7	December 16, 1811	New Madrid, MO
7.7	February 7, 1812	New Madrid, MO
7.5	January 23, 1812	New Madrid, MO
7.4	March 26, 1872	Owens Valley, CA
7.3	June 28, 1992	Landers, CA
7.3	August 18, 1959	Hebgen Lake, MT

Source: U.S. Geological Survey. 2010. http://earthquake.usgs.gov/earthquakes/states/10_largest_us.php

Facts

- Earthquakes in the central or eastern United States affect much larger areas than earthquakes of similar magnitude in the western United States. For example, the San Francisco, California earthquake of 1906 (magnitude 7.8) was felt 560 miles away in the middle of Nevada, whereas the New Madrid earthquake of December 1811 (magnitude 7.7) rang church bells in Boston, Massachusetts, 1,600 miles away. Geology differences east and west of the Rocky Mountains account for this strong contrast.
- Earthquakes similar to the New Madrid earthquake series of 1811 -1812 and the San Francisco earthquake of 1906 could cause over $500 billion in damage.
- Annually, there are an average of six (6) earthquakes with a 6 or greater magnitude and fifty-seven earthquakes with magnitudes of 5 or greater in the United States.
- Currently, twenty-six urban and metropolitan areas in the U.S. are at risk of being affected by significant seismic activity.
- The largest earthquake ever recorded in the U.S. was a magnitude 9.2 in Prince William Sound, Alaska in March of 1964.
- Almost 6,000 earthquakes occurred on average each year from 2010-2012 in the United States.
- Over 20,000 earthquakes occurred on average each year from 2010-2012 worldwide.



The USGS National Seismic Hazard Maps display earthquake ground motions for various probability levels across the United States. Based on peak ground acceleration (PGA) the following map shows high risk areas to earthquake effects.

Impacts

Ground shaking from earthquakes can collapse buildings and bridges, disrupt gas, electric, and phone service among other disruptions, and sometimes trigger landslides, avalanches, dam failure, flash floods, fires, and huge, destructive ocean waves (tsunamis). Buildings with foundations resting on unconsolidated landfill and other unstable soil, and trailers and homes not tied to foundations are at risk of being shaken off their mountings during an earthquake. When an earthquake occurs in a populated area, it may cause deaths, injuries, and extensive property damage.

Between 2000 and 2012, an average of 62,600 people worldwide died annually due to earthquakes. Small tremors that occur after the initial earthquake has dissipated often make it difficult for those participating in rescue and rebuilding efforts to aid the populations most affected. These delays cause further loss of life and prolong the displacement of families and individuals. The January 1994 earthquake in Northridge, California, for example, killed 60, injured 9,000, and displaced over 20,000 people.

FEMA has estimated future losses due to earthquakes in the United States at $5.6 billion each year, with more earthquakes occurring on the West coast than the East coast, though the Central and Eastern portions of the country remain at a high risk of damage due to geologic factors, magnified by the lack of structures built to withstand such disasters. Thus, the USGS has named earthquakes the natural disaster most likely to cause catastrophic casualties, property damage, and economic disruption.

Profiling Hazards: Earthquake

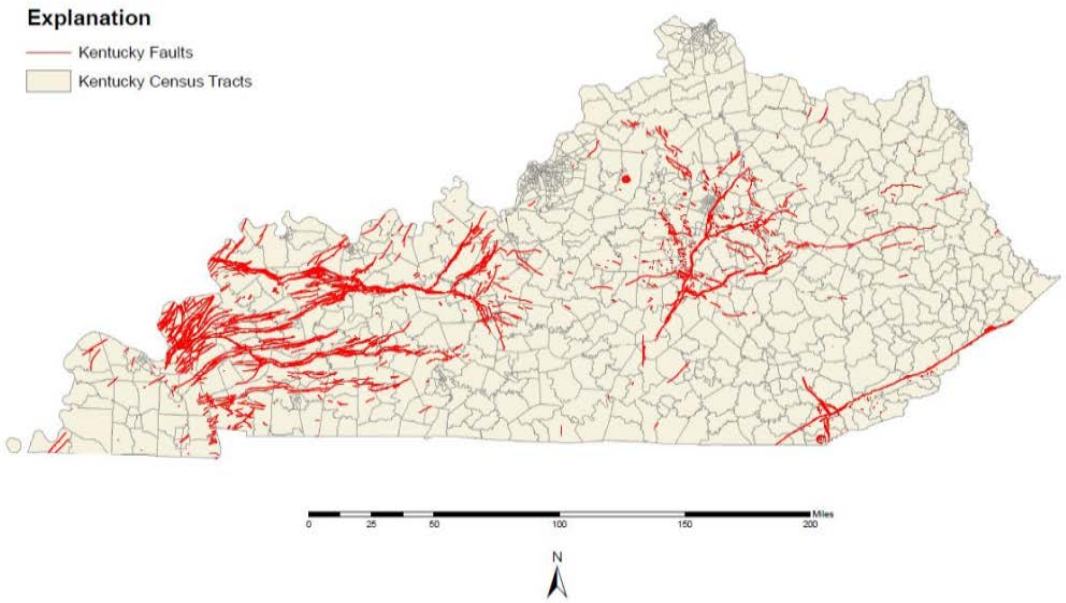
EARTHQUAKE PROFILE RISK TABLE	
Period of occurrence:	Earthquakes can occur year-round, at any time of the day or the night
Number of events: (1960-2013)	1*
Annual Rate of Occurrence:	Currently there are no probability ratios determined for earthquakes because of its unpredictable nature.
Warning time:	Warning time is essentially non-existent, as geologic activity at fault lines in the earth's crust happen sporadically.
Potential impacts:	Earthquakes can heavily impact human life, health, and public safety. Large events can cause infrastructure damage, utility damage, and critical facilities damage. Secondary events often trigger landslides, dam failure/flooding, and may facilitate the release of hazardous materials from containment structures.
Recorded losses:	$2,763,158*
Annualized Loss:	$52,135
Extent (Historical & Scale)[2]:	Year: 1980 Scale: 5.2 Location: Bath County

*Data captured from SHELDUS 10.1 (occurrence data captures county-level events across the state)

Fault lines run through much of Kentucky, with each of the fifteen area development districts (ADDs) containing at least one fault line or fault system. A number of these systems have remained geologically inactive for significant amounts of time, but scientists believe some are overdue for a surge in activity.

[2] The extent to which an earthquake can possibly wreak havoc to the Commonwealth of Kentucky is implicit in the citation of Modified Mercalli Intensity Scale. However, this plan also reports an historical account by which to judge extent: In 1980, Bath County experienced a particularly destructive earthquake that measured a 5.2 on the Modified Mercalli Intensity Scale.

Kentucky Fault Lines



Source: U.S. Geological Survey. 2008 http://earthquake.usgs.gov/research/hazmaps/products_data/2008/maps/

The three (3) seismic zones most likely to put Kentucky at risk are centered outside of the state, but pose a very real threat to the Commonwealth's citizens.

1. *The Eastern Tennessee Seismic Zone* extends from southwest Virginia to northeast Alabama and is one of the most seismically active fault systems in the Southeast. Although the zone has not experienced a large earthquake in historic times, a few minor earthquakes have caused slight damage. The largest recorded earthquake in this seismic zone was a magnitude 4.6 which occurred in 1973 near Knoxville. Sensitive seismographs have recorded hundreds of earthquakes too small to be felt in this seismic zone. Small, non-damaging, felt earthquakes occur about once a year. No evidence for larger prehistoric shocks has been discovered, yet the micro-earthquake data suggest coherent stress accumulation within a large volume. Physical processes for reactivation of basement faults in this region could involve a weak lower crust and increased fluid pressures within the upper to middle crust.
2. *The New Madrid Seismic Zone (NMSZ),* located in the central Mississippi Valley, is generally demarked on the north by the confluence of the Ohio and Mississippi Rivers. From this point in southern Illinois, the zone runs southwest, through western Kentucky (near Fulton), through eastern Missouri and western Tennessee and terminates in northeastern Arkansas, crossing the Mississippi River three (3) times.

3. *The Wabash Valley Seismic Zone* which threatens southern Illinois, Indiana, and Kentucky, shows evidence of large earthquakes in its geologic history. Since 1895, The Wabash Valley Fault Zone has experienced more moderate quakes than the New Madrid Seismic Zone. Some prehistoric quakes which occurred in this zone between 4,000 and 10,000 years ago may have been larger than M6.0. Earthquake ground shaking is amplified by lowland soils, and modern earthquakes of M5.5 to 6.0 in the Wabash Valley Fault Zone could cause substantial damage if they occur close to the populated river towns and cities along the Wabash River and tributaries.

The most notable earthquake or series of earthquakes in Kentucky occurred along the New Madrid Seismic Zone from December 1811 to March 1812. Three (3) of the largest earthquakes in the contiguous United States occurred along this zone during this period. An engineer in Louisville recorded approximately 1,850 quakes throughout the four-month timeframe. The shocks from these earthquakes could be easily felt as far away as Michigan and South Carolina. An area between the St. Francois River and Mississippi River running from New Madrid, Missouri to Marked Tree, Arkansas showed numerous sand-blows (a place where liquefacted alluvial soil has geysered through the surface).

Earthquake Occurrences (1834-2003)			
Date	Location	Richter/Mercalli Value	Description
Nov. 20, 1834	Northern KY		Houses shook and plaster cracked
Dec. 27, 1841	Hickman, KY		Houses shook and Mississippi River was agitated, though no wind was blowing
January 4, 1843	Mississippi Valley		Small earthquakes were reported, but no damages or first-hand accounts of intensity were reported
Feb. 16, 1843	Mississippi Valley		Small earthquakes were reported, but no damages or first-hand accounts of intensity were reported.
March 12, 1878	Columbus, KY		A severe shock caused sections of bluff line along the Mississippi River to cave in
Dec. 7, 1915	Western Kentucky	Intensity V, VI	Buildings were strongly shaken, windows and dishes rattled, and loose objects were thrown to the floor
Oct. 26, 1916	Mayfield, KY	Intensity V	Pictures were shaken from walls
Dec. 18, 1916	Hickman, KY	Intensity VI, VII	Houses shook and chimneys partially toppled
March 2, 1924	Western Kentucky		No significant damages were reported
Sept. 2, 1925	Henderson, KY		Caused landslides and damage to a number of properties, including a chimney that was toppled in Louisville, over 100 miles away from the epicenter. Illinois, Indiana, and Tennessee were also affected.
Jan. 1, 1954	Middlesboro, KY	Intensity VI	Slight damages were reported. The tremor was felt in Tennessee, North Carolina, and Virginia.
Nov. 9, 1958	Henderson, KY	Intensity VII	Substantial masonry damage was sustained in Henderson. Significant damage was also reported in Poole, Smith Mills, and Uniontown, as well as part of southern Illinois, Indiana, and Missouri.
Nov. 9, 1968	Statewide		Strongest earthquake reported in Kentucky since 1895; affected 23 states

Earthquake Occurrences (1834-2003)			
Date	Location	Richter/Mercalli Value	Description
1977	Statewide		Originating at the Wabash Valley Fault, at least one chimney in Louisville was destroyed. earthquake, was felt by most of the Midwest.
1980	Bath County	5.2	The earthquake was recorded near Sharpsburg and was felt over all or parts of 15 State and in Ontario, Canada. Damage occurred in Indiana, Kentucky, and Ohio.
2003	Western Kentucky	4.0	Slight damage (VI) at Bardwell. Felt (V) at Arlington; (IV) at Clinton, Fulton and Wickliffe; (III) at Cunningham, Kevil, Paducah, and West Paducah. Felt in western Kentucky and in parts of Arkansas, Illinois, Indiana, Missouri, and Tennessee.

During the 1811-1812 earthquakes, notable geologic changes occurred on the landscape. Land masses along the Mississippi River were uplifted, while others subsided. Opposite New Madrid, Missouri for example, in the area around Tiptonville, Tennessee, a dome was formed that uplifted several yards. Immediately adjacent to the Tiptonville Dome, an area subsided to form a lake eighteen miles long and five miles wide, now known as Reelfoot Lake and used as a tourist and recreation area.

Ground failure and landslides were apparent throughout the Chickasaw Bluffs alongside the Mississippi River in Kentucky and Tennessee, with many fissures created throughout the region. One local observer reported that while watching the fissures form, the earth seemed to be rolling in waves several feet in height.

The damage to the area was so severe, Congress passed and President James Madison signed into law, the first disaster relief act which gave citizens in the affected area the option to obtain government lands in other territories due to the devastation that disaster had caused.

The strongest earthquake in the history of Kentucky was recorded on July 27, 1980, near Sharpsburg in Bath County, Kentucky. It registered at a magnitude of 5.2 on the Richter Scale and an Intensity VII on the Mercalli Scale. This earthquake was felt over all or parts of 15 States and in Ontario, Canada. Damage occurred in Indiana, Kentucky, and Ohio.

Property damage was estimated at $1 million at Maysville, Kentucky which is in Mason County about 50 kilometers north of the epicenter, where 37 commercial structures and 269 private residences were damaged to some extent. Multistory all-brick structures in the downtown area, many of which were built in the mid-1800s, were affected the most. Broken chimneys represented the most common type of damage observed: several toppled or were broken at or near the roofline, some had bricks loosened or broken off their tops, and others sustained cracks of varying

lengths and widths. This type of damage was a community-wide effect only in Maysville.

Cracks formed in the ground about 12 kilometers from the epicenter. East of the epicenter, at Owingsville, ground cracks were estimated to be 6 to 10 centimeters deep and 30 meters long. West of the epicenter, near Little Rock, ground cracks extending toward a cistern were observed on Stoner Road.

Assessing Vulnerability by Jurisdiction: Earthquake

Grid-Level Risk Assessment Model

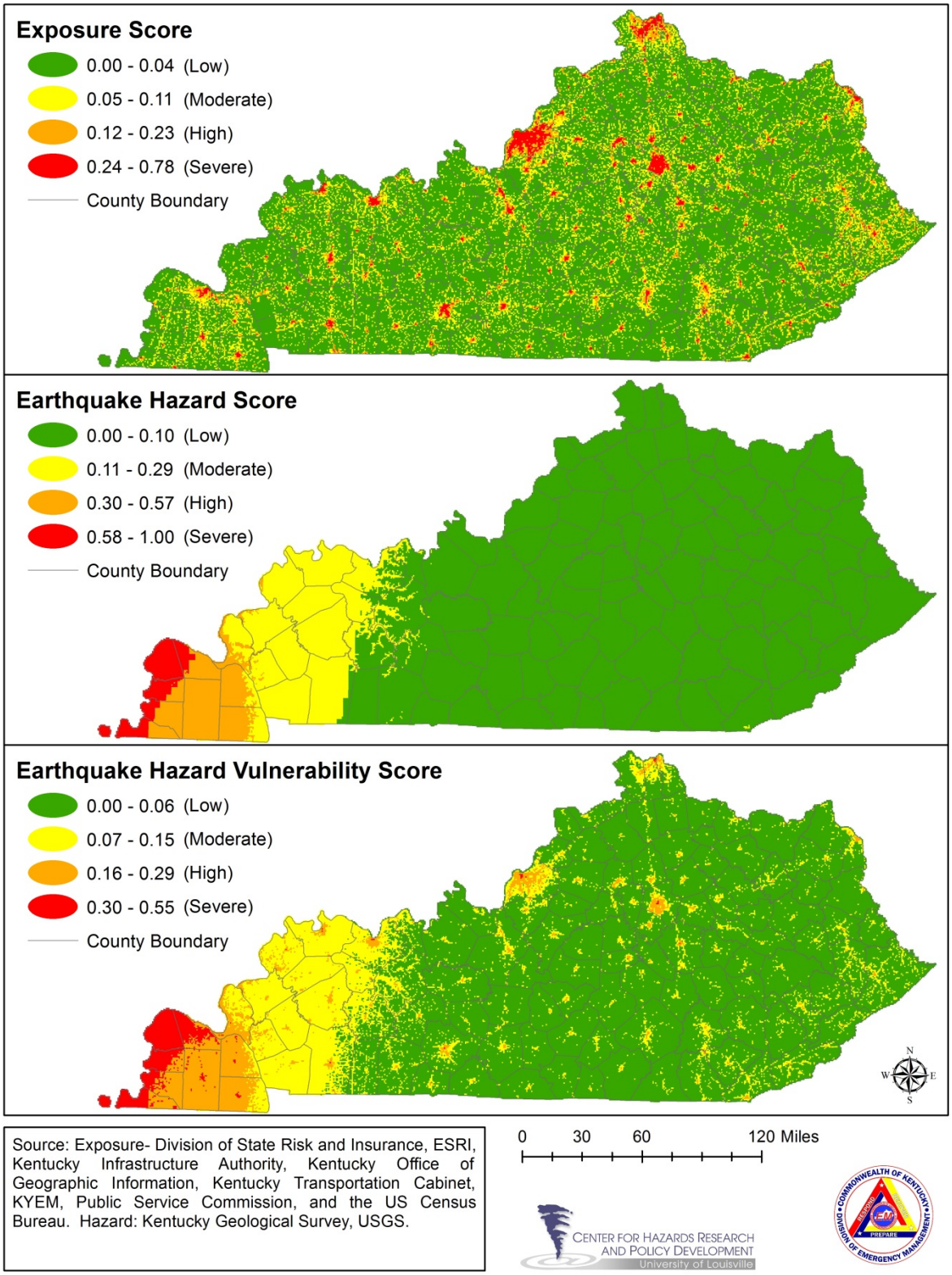
Earthquake Vulnerability Score = Exposure Score + Hazard Score

Assessing Kentucky's vulnerability to earthquake was determined through first calculating the Earthquake Hazard Score. The Earthquake Hazard Score was calculated by studying two (2) sources of data. The two (2) layers used were the USGS 2% chance in 50 years peak ground acceleration (PGA) data modified by the NEHERP soil amplification data provided by the Kentucky Geological Survey (KGS). Using FEMA's HAZUS technical manual methodology CHR modified USGS 2% chance in 50 years PGA data using NEHERP soil classification to modify PGA values based on Kentucky soil types. Combining these layers provided enhanced soil classifications for Kentucky which were used to compute soil amplifications. Next, a calculation was computed based on the average modified PGA value located within each grid. This average PGA value for each 1KM MGRS grid was then calculated and scored 0-1 to develop the Earthquake Hazard Score.

Finally, the Earthquake Vulnerability Score was calculated for each 1 KM MGRS grid by adding each grid's Exposure Score by its Earthquake Hazard Score and then scored 0-1. Once the final Earthquake Vulnerability Scores were calculated the composite scores were broken into four (4) categories, using the Natural Breaks classification system (1. Low, 2. Moderate, 3. High, 4. Severe) which demonstrates different levels of vulnerability displayed on the map.

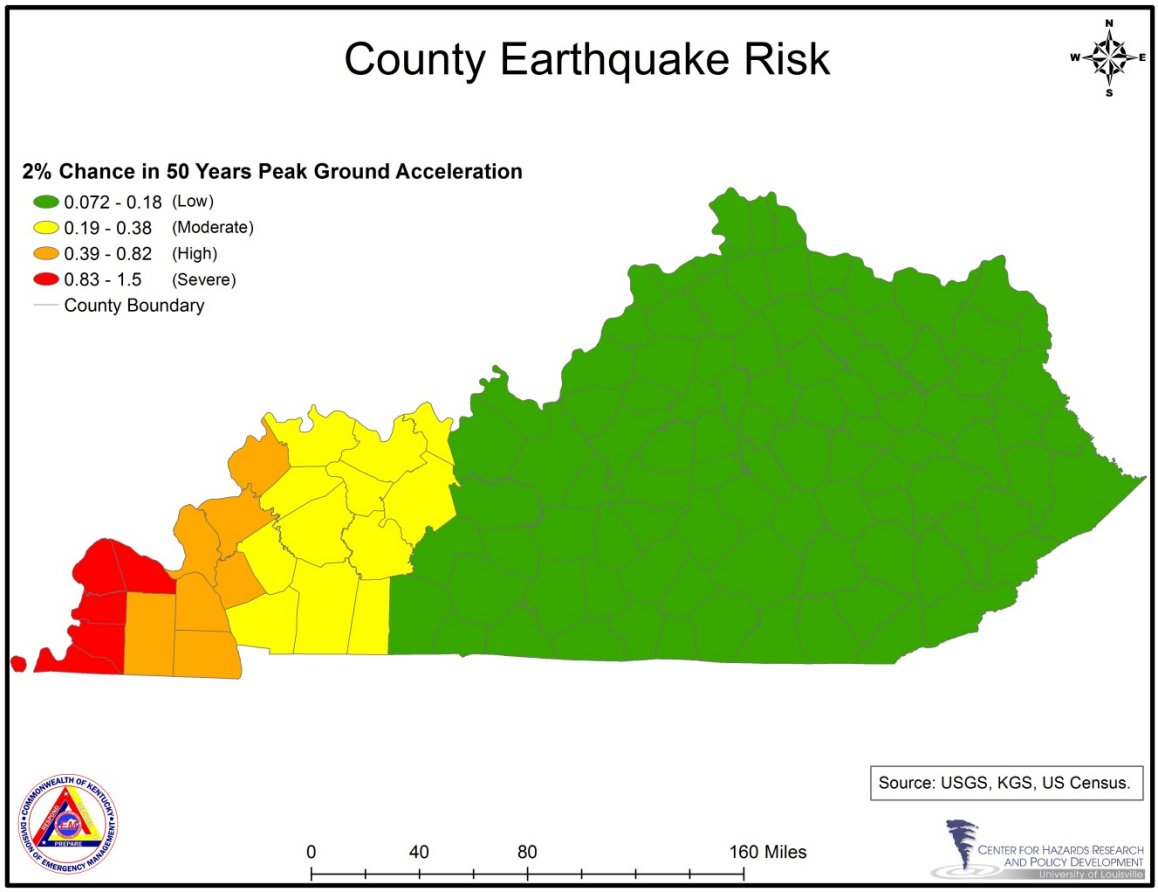
The Grid-Level Risk Assessment Model should be used to identify specific areas of vulnerability located throughout Kentucky. This model provides 106,178 equal areas of comparison for the end users to assess hazard vulnerability. The best way to view and use this data is through a GIS viewer.

The following map displays the maps and components of the Earthquake Vulnerability Score.



County-Level Risk Assessment Model

The Earthquake County Risk Assessment Model was created using the modified earthquake NEHERP soil PGA. The average PGA was calculated for each county and then joined to a county map for display as seen below.



The County-Level Risk Assessment Model should be used to compare county-level risk. This data depicts which counties are most likely to experience damaging earthquakes.

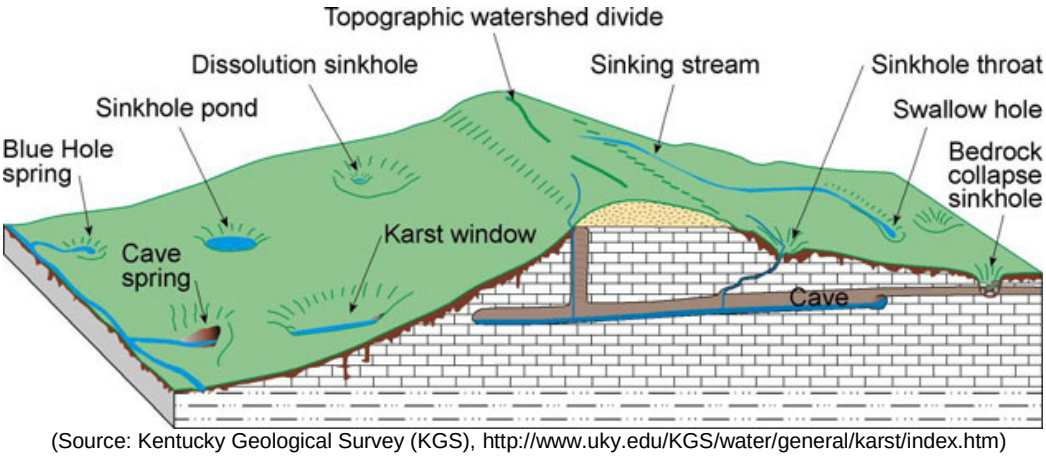
Karst/Sinkhole

Identifying Hazards: Karst/Sinkhole

Description

A term stemming from a Slavic word meaning “barren, stony ground”, Karst refers to *a terrain with distinctive landforms and hydrology created from the dissolution of soluble rock—such as limestone and other carbonate rocks—and is characterized by springs, caves, sinkholes, and a unique hydrology*.

Karst topography is formed by the erosion of rock due to rain and underground water and is primarily characterized by closed depressions or sinkholes and underground drainage. During the formation of karst terrain, water percolating underground enlarges subsurface flow paths by dissolving the rock. As some subsurface flow paths are enlarged over time, water movement beneath the surface changes character from one in which ground water flow is initially through small, scattered openings in the rock, to one where the majority of the flow is concentrated in a few, well-developed conduits. As the flow paths continue to enlarge, caves may be formed and the ground water table may drop below the level of surface streams and these streams may then begin to lose water to the subsurface. As more of the surface water is diverted underground, surface streams and stream valleys become a less conspicuous feature of the land surface, and are replaced by closed basins. Funnels, or circular depressions called sinkholes, often develop at some places in the low points of these closed basins.



(Source: Kentucky Geological Survey (KGS), http://www.uky.edu/KGS/water/general/karst/index.htm)

Most commonly seen in karst landscapes, sinkholes are defined as *concentrated areas of depressed landscape due to spaces and caverns that have developed underground in soluble rocks by the groundwater running through them*. Sinkholes may vary in area from a just a few square feet to over 100 acres and may vary in depth from just under one (1) foot to over 100 feet deep; though they typically average ten to thirty feet in depth. Most often sinkholes develop slowly over very long periods of time, but occasionally the collapse of large sinkholes cause substantial changes to the landscape and pose a threat to human populations and

structures in the immediate area. The presence of karst topography and sinkholes poses a threat not only to populations and built structures, but poses a significant threat to groundwater supplies as well. For the purposes of this document, however, the focus will remain on the potential risk caused by the development of karst topography and sinkholes in terms of potential damage sustained by structures and harm posed to human populations.

Due to unique geological composition, Florida, Texas, Alabama, Missouri, Kentucky, Tennessee, and Pennsylvania are the most at-risk states in the U.S. in terms of experiencing karst/sinkhole related events. But, approximately 20 percent of the land surface in the U.S. is classified as karst.

Because sinkholes are often very large in size, many are improperly classified as other geologic phenomena and structures are built on them. Agencies in some states are working jointly to assess the geologic composition of the terrain in conjunction with zoning laws in regions where karst/sinkholes appears to be a problem.

Sinkhole plain before a rain. **Sinkhole plain after a rain.**

Good indicators of the development of sinkholes include; circular and linear cracks in soil, asphalt, and concrete paving and floors; depressions in soil or pavement which commonly result in ponds of water; slumping, sagging, or tilting of trees, roads, rails, fences, pipes, poles, sign boards, and other vertical or horizontal structures; downward movement of small-diameter vertical or horizontal structures; fractures in foundations and walls, often accompanied by jammed doors and windows; small conical holes that appear in the ground over a relatively short period of time; sudden muddying of water in a well which has been producing clear water; and sudden draining of a pond or creek.

Types

Sinkholes develop in a number of ways and can be categorized into five types.

1. *Collapse sinkholes* occur when the bridging material over a subsurface cavern cannot support the overlying material. The cover collapses into the cavern and a large, funnel-shaped depression forms.

2. *Solution sinkholes* result from increased groundwater flow into higher porosity zones within the rock, typically through fractures or joints within the rock. An increase of slightly acidic surface water into the subsurface continues the slow dissolution of the rock matrix, resulting in slow subsidence as surface materials fill the voids.

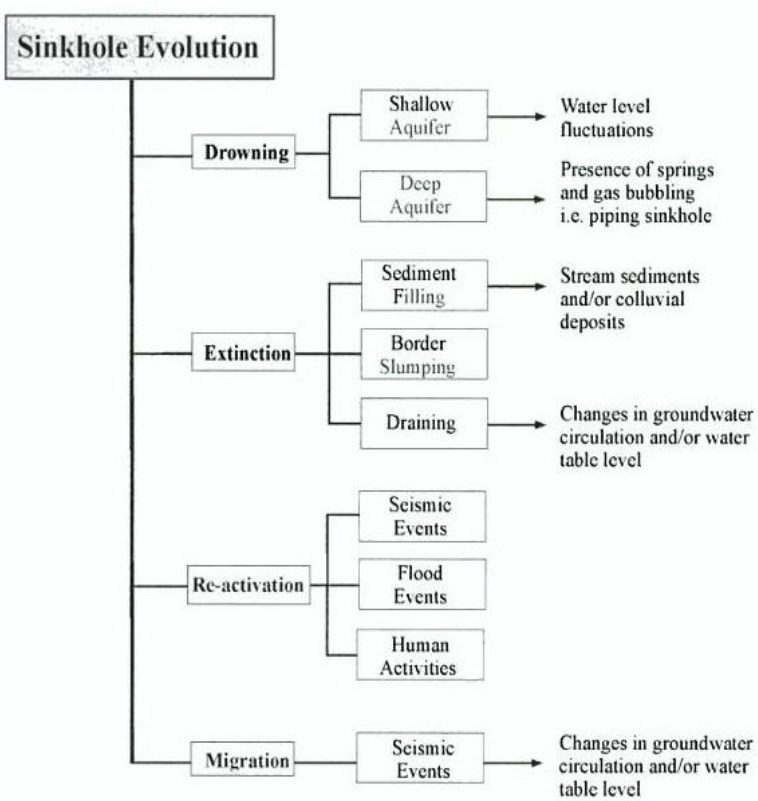
3. *Alluvial sinkholes* are older sinkholes which have been partially filled with marine, wetland, or soil sediments. These features are common in places like Florida, where the water table is shallow, and typically appear as shallow lakes, cypress domes, and wetlands.

4. *Raveling sinkholes* form when a thick overburden of sediment over a deep cavern caves into the void and pipes upward toward the surface. As the overlying material or plug erodes into the cavern, the void migrates upward until the cover can no longer be supported and then subsidence begin

5. *Cover-Collapse sinkholes* occur in the soil or other loose material overlying soluble bedrock. Sinkholes that suddenly appear form in two ways. In the first way, the bedrock roof of a cave becomes too thin to support the weight of the bedrock and the soil material above it. The cave roof then collapses, forming a bedrock-collapse sinkhole. Bedrock collapse is rare and the least likely way a sinkhole can form, although it is commonly incorrectly assumed to be the way all sinkholes form. The second way sinkholes can form is much more common and much less dramatic. The sinkhole begins to form when a fracture in the limestone bedrock is enlarged by water dissolving the limestone. As the bedrock is dissolved and carried away underground, the soil gently slumps or erodes into the developing sinkhole. Once the underlying conduits become large enough, insoluble soil and rock particles are carried away too. Cover-collapse sinkholes can vary in size from 1 or 2 feet deep and wide, to tens of feet deep and wide. The thickness and cohesiveness of the soil cover determine the size of a cover-collapse sinkhole.

Facts

- A karst landscape most commonly develops on limestone, but can develop on several other types of rocks, such as dolostone, gypsum, and salt.
- Evaporite rocks (the most soluble of common rocks), which includes gypsum and salt, underlie 35% to 40% of the U.S., though sometimes they are buried deep below the surface.
- Karst landscapes make up one-fifth of the world's land surface. The American Southeast has a proportion almost doubling that of other karstic regions of the world.
- Sixty times more fresh water lies beneath the Earth's surface than on it, so karst landscapes and their underground streams, springs, and aquifers have played a key role in supplying water to various populations for thousands of years.
- A few famous karst areas in the United States include Carlsbad Caverns in New Mexico, the many springs of Florida, and the Mammoth Cave system in Kentucky.
- Some geologists believe that sinkhole activity increases after periods of prolonged drought.
- The evolution of a sinkhole is proposed as looking like:



Impacts

The effects of sinkholes and other features typically present in karst terrain vary from the mild to the extreme and can no doubt wreak havoc on infrastructure in urban areas. Storm-water drainage is of major concern in urban areas underlain by karst geology, as the ground surface area necessary for the even infiltration of rainwater into the groundwater supply system is covered with impervious substances such as blacktop and cement. This imbalance can often have serious consequences, leading to movement of the ground which may rupture sewer lines, natural gas lines, or effect underground utility lines.

For example, in 2009, a fire truck in a Los Angeles suburb was pulled into a sinkhole that was caused by a series of pipe ruptures that stemmed from geologic phenomena. And, in 1994, an area underlain by karst produced a sinkhole the size of a small house that jeopardized Allentown, Pennsylvania's newest office building and thoroughfare. Allentown filled the sinkhole using over 700 cubic yards of concrete. The most recent national sinkhole news was about a man who was swallowed by a sinkhole that suddenly opened under his bedroom in Sefner, Florida on February 28, 2013. The depression formed by the collapse was 30 feet wide and 20 feet deep.

Groundwater contamination is also more prevalent in areas of karst geology, as percolation occurs more quickly. Contaminants such as oil from automobiles in parking lots, pesticides and herbicides from lawns, and urine and feces from cattle feed lots end up in water supplies used by surrounding communities. This type of contamination is particularly dangerous in areas where private wells are used instead of water that comes from public works. If allowed to filter naturally, an underground water source will take up to 100 human generations to filter its impurities.

Some states now have enacted insurance legislation which provides property owners affected by sinkholes some piece of mind, but most states have yet to specifically address the issue.

Profiling Hazards: Karst/Sinkhole

KARST/SINKHOLE PROFILE RISK TABLE	
Period of occurrence:	At any time
Number of events: (Unknown)	101,632 Identified Sinkholes*
Annual Rate of Occurrence:	Unknown due to lack of start and end dates
Warning time:	Weeks to months, depending on monitoring and maintenance
Potential impacts:	Economic losses such as decreased property value and agribusiness losses, and may cause minimal to severe property damage and destruction, may cause geological movement, causing infrastructure damages.
Recorded losses:	Unknown
Annualized Loss:	Unknown due to lack loss data captured on Karst/Sinkhole events
Extent (Statistical)[3]:	Location: 55% of State with rocks susceptible to developing karst terrain Size: On average 7 ft. in diameter[4]

*Data captured from Kentucky Geological Survey

[3] The fact that sinkhole events are so common throughout Kentucky that seldom are events reported to central authorities: "Most noticeable are sinkhole flooding and cover collapse. Damage to infrastructure from these two causes is so common in Kentucky that it is typically dealt with by local authorities as a routine matter. Seldom are collapses reported to any central agency."

- *Source:* Cobb, Jim and James C. Currens. [May 2001]. "Karst: The Stealthy Hazard." *Geotimes*. American Geological Institute: http://www.geotimes.org/may01/feature2.html [Last accessed: 2/22/2013]

Still: "Some sinkholes [in Kentucky] are up to several hundred feet in diameter and more than 100 feet (30m) deep…Sinkholes are so numerous in…Pennyroyal that rainwater disappears underground before it has a chance to form surface streams [Palmer 1981, p. 38]."

- *Source:* Palmer, Arthur N. [1981]. *A Geological Guide to Mammoth Cave National Park*. Teaneck, NJ: Zephyrus Press.

And Bowling Green, Kentucky houses one of the largest sinkholes…in the world! The ***Trimodal TransPark*** sinkhole is ***200 feet wide,*** and ***35 feet deep***! It is ranked one of the "5 Giant Holes That Devoured Everything Around Them" by *Environmental Graffiti*, which is an environmental news-aggregating website.

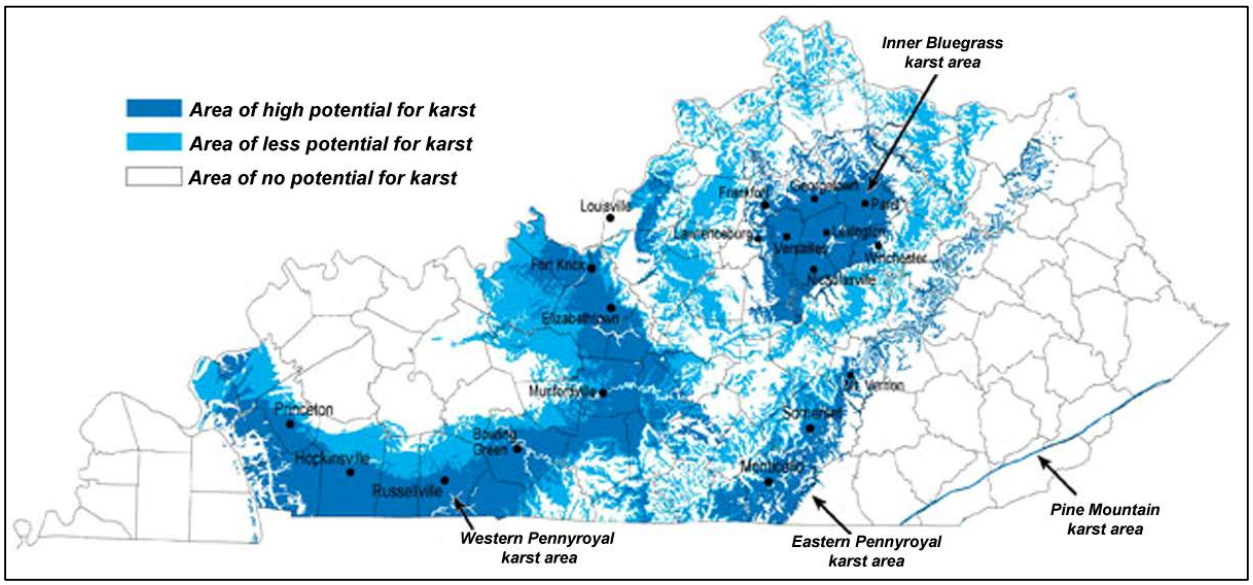
- § *Source:* Anonymous. [Date Unspecified]. "5 Giant Holes That Devoured Everything Around Them." *Environmental Graffiti*. *Can be accessed:* http://www.environmentalgraffiti.com/offbeat-news/5-giant-holes-devoured-everything-around-them/1196?image=6. [Last accessed: 2/22/2013].

The ***Trimodal TransPark*** sinkhole also is ranked by *WebEcoist* as one of the 13 "Biggest, Strangest, Most Devastating Sinkholes on Earth."

- § *Source:* Ecoist. [2012]. "13 of the Biggest, Strangest, Most Devastating Sinkholes on Earth." *WebEcoist*. Evolve Media: AtomicOnline, LLC. *Can be accessed:* http://webecoist.momtastic.com/2008/08/26/incredible-strange-amazing-sinkholes/ [Last accessed: 2/22/2013].

[4] As karst more describes terrain and the *eventual* or *probabilistic cause* of hazards, a statistical average has been used to describe "extent." In the spirit of "extent" and like using a scale or an historical extreme, the statistical average diameter of karst terrain acts a standard by which to compare individual "karst hazard events."

Kentucky is one of the most famous karst areas in the world. Much of the state's beautiful scenery, particularly the horse farms of the Inner Bluegrass, is the result of development of karst landscape. The karst topography of Kentucky is mostly on limestone, but also some dolostone. The areas where those rocks are near the surface closely approximate where karst topography will form. The following map shows the outcrop of limestone and dolostone and closely represents the karst areas. The bedrock is millions of years old and the karst terrain formed on them is hundreds of thousands of years old. In humid climates such as Kentucky's it is assumed that all limestone has karst development, although that development may not be visible at the surface.



Source: KGS, http://www.uky.edu/KGS/water/general/karst/where_karst.htm

The outcrop area of the limestone bedrock in Kentucky has been used to estimate the percentage of karst terrain or topography in the state. About 55 percent of Kentucky is underlain by rocks that could develop karst terrain, given enough time. About 38 percent of the state has at least some karst development recognizable on topographic maps and 25 percent of the state is known to have well-developed karst features. Some Kentucky cities located on karst include (in the Inner Bluegrass) Frankfort, Louisville, Lexington, Lawrenceburg, Georgetown, Winchester, Paris, Versailles, and Nicholasville; (in the Western Pennyroyal) the communities of Fort Knox, Bowling Green, Elizabethtown, Munfordville, Russellville, Hopkinsville, and Princeton; (in the Eastern Pennyroyal) Somerset, Monticello, and Mount Vernon.

Springs and wells in karst areas supply water to tens of thousands of homes. Much of Kentucky‘s prime farmland is underlain by karst, as is a substantial amount of the Daniel Boone National Forest with its important recreational and timber resources. Caves are also important karst features, providing recreation and unique ecosystems. Mammoth Cave is the longest surveyed cave in the world, with more than 400 miles of passages. Two (2) other caves in the state stretch more than 30

miles, and nine (9) Kentucky caves are among the 50 longest caves in the United States.

Because of these formations, Kentucky is ranked fifth in the nation of states affected by sinkholes. The most noticeable hazards in Kentucky in regards to sinkholes are sinkhole flooding and cover collapse. Damage to infrastructure from these two (2) causes is so common in Kentucky, in fact, that it is typically dealt with by local authorities as a routine matter and collapses are seldom reported to any central agency.

Previous Occurrences

In Kentucky, infrastructure damage from karst is common, as a number of dams are built in karst areas. For example, Wolf Creek Dam, located on the Cumberland River in the Western part of Russell County, Kentucky in southeastern Kentucky, was constructed in the 1940s on permeable Lower Mississippian calcareous siltstones interbedded with reef carbonates, Devonian black shale, and Upper Ordovician dolomites. Although karst conduits and caves were encountered and remediated, the extent of karst development at the site was not fully recognized during construction. In the late 1960s, sinkholes developed near the downstream toe of the dam where reservoir water was passing beneath the cutoff trench. The problem was solved with a diaphragm cutoff wall nearly 4,500 feet long and up to 278 feet deep. The repairs cost millions of dollars and could have been avoided if the original builders had obtained better on-site geological data.

Throughout the state, many other reservoirs of all sizes have leaking dams or leakage through carbonate bedrock around the dam, including leakage through caves passing under the dam of Shanty Hollow Lake in Warren County and leakage through bedrock that forms the abutment bank of Spa Lake in Logan County.

Highways are also vulnerable. In the mid-1990s, a cover-collapse sinkhole appeared overnight in the northbound lane of Interstate 65 near Elizabethtown. Fortunately, no one drove into it, but it did require extensive repairs. Exceptional costs for highway construction projects and repairs to existing roadways since 1995 are estimated to exceed a half million dollars a year.

The Kentucky Department of Emergency Services estimates that a March 1997 sinkhole flood cost more than $1 million in mitigation costs alone -- including buyouts and construction of storm water detention basins for a few counties in the central and western Kentucky karst areas. The Kentucky Geological Survey has been part of efforts to address karst-related flooding problems in several cities in the Inner Bluegrass and Western Pennyroyal since 1990. Sinkhole flooding in Bowling Green (Warren County) is well known and has prompted the county to enact strict zoning regulations and building codes. The city of Versailles has spent over $500,000 to purchase flood-damaged property in order to take remedial action. These sites suggest the average annual loss statewide exceeds $1 million from flood damage alone.

In 2008, Louisville Metro Government introduced local karst regulations which were adopted by Louisville Metro Government Council. These regulations are now part of the Louisville Development Code. The new regulations assigns responsibility to the Louisville Metro Government Planning and Design Services for the receipt and reporting of information regarding karst/sinkhole locations indicated on development plans.

Assessing Vulnerability by Jurisdiction: Karst/Sinkhole

Grid-Level Risk Assessment Model

Karst/Sinkhole Vulnerability Score = Exposure Score + Hazard Score

Assessing Kentucky's vulnerability to karst/sinkhole was determined through first calculating the Karst/Sinkhole Hazard Score. The Karst/Sinkhole Hazard Score was calculated by studying two (2) sources of data. Each of the datasets was provided by the Kentucky Geological Survey (KGS). The first layer used to create the Karst/Sinkhole Hazard Score was the KGS developed Minor and Major karst GIS layer. The KGS karst layer displays a geo-referenced data layer that depicts where karst is located. To analyze Kentucky's risk to karst/sinkhole, the karst layer was overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based on the percent of the area the karst layer covered within each grid. This percentage of area affected by the mapped karst potential area was then calculated and scored 0-1 to develop 50% of the Karst/Sinkhole Hazard Score.

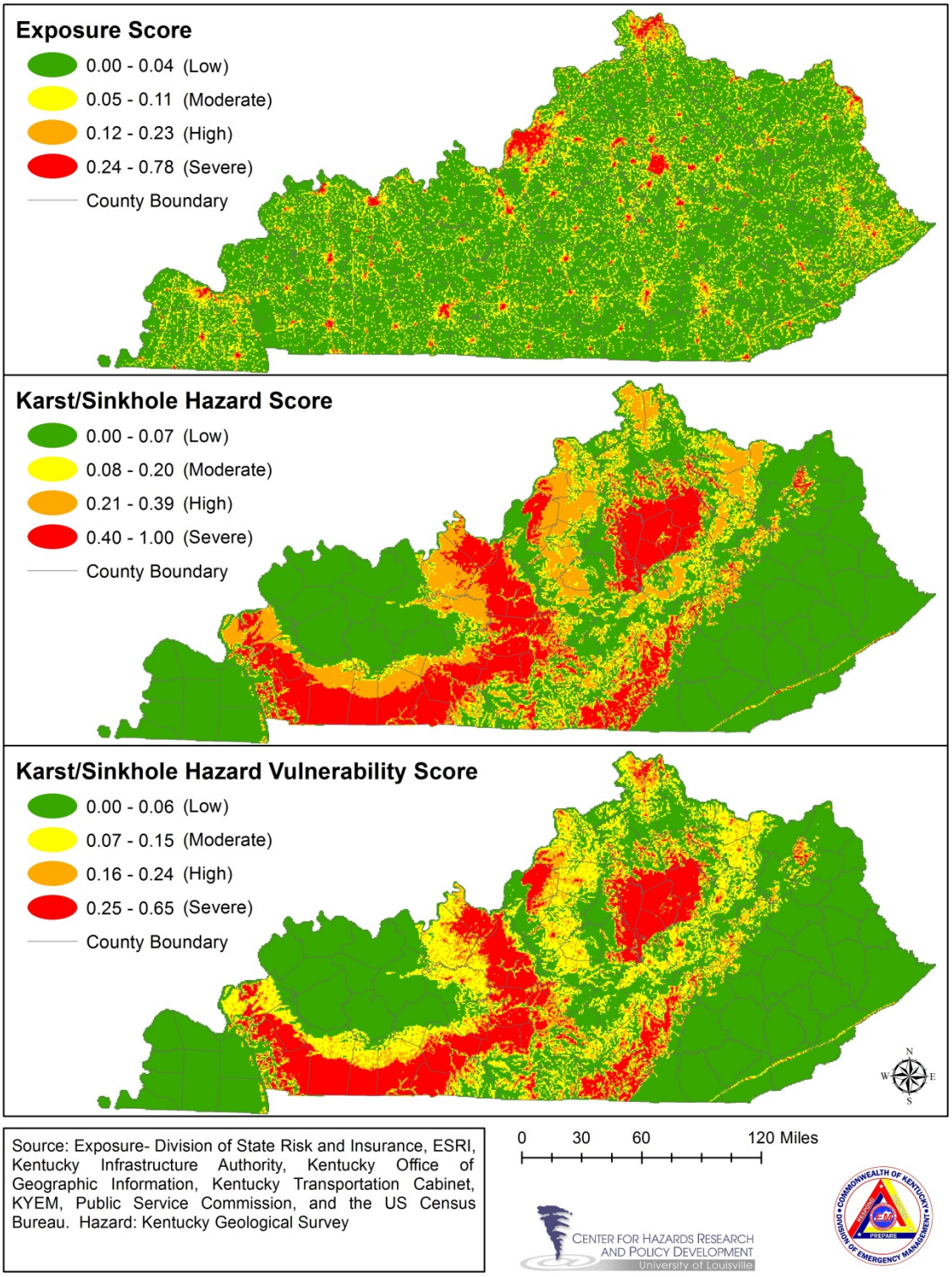
The next step was determined by calculating the percent area affected by a sinkhole polygon GIS layer provided by KGS. This data displayed where concentrations of sinkhole events have occurred, thus producing areas of risk. The KGS sinkhole layer displays a geo-referenced data layer that depicts where sinkholes have occurred. To analyze Kentucky's risk to karst/sinkhole, the sinkhole layer was overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based on the percent of the area the sinkhole layer covered within each grid. This percentage of area affected by the mapped sinkhole areas was then calculated and scored 0-1 to develop 50% of the Karst/Sinkhole Hazard Score.

The Karst/Sinkhole Hazard Score was then calculated by adding the two (2) scores together and scored 0-1. It is important to note if the Karst/Sinkhole Hazard Score inputs equaled 0, then the Karst/Sinkhole Hazard Vulnerability Score equaled 0.

Finally, the Karst/Sinkhole Vulnerability Score was calculated for each 1 KM MGRS grid by adding each grid's Exposure Score by its Karst/Sinkhole Hazard Score and then scored 0-1. Once the final Karst/Sinkhole Vulnerability Scores were calculated the composite scores were broken into four (4) categories, using the Natural Breaks classification system (1. Low, 2. Moderate, 3. High, and 4. Severe) which demonstrates different levels of vulnerability displayed on the map.

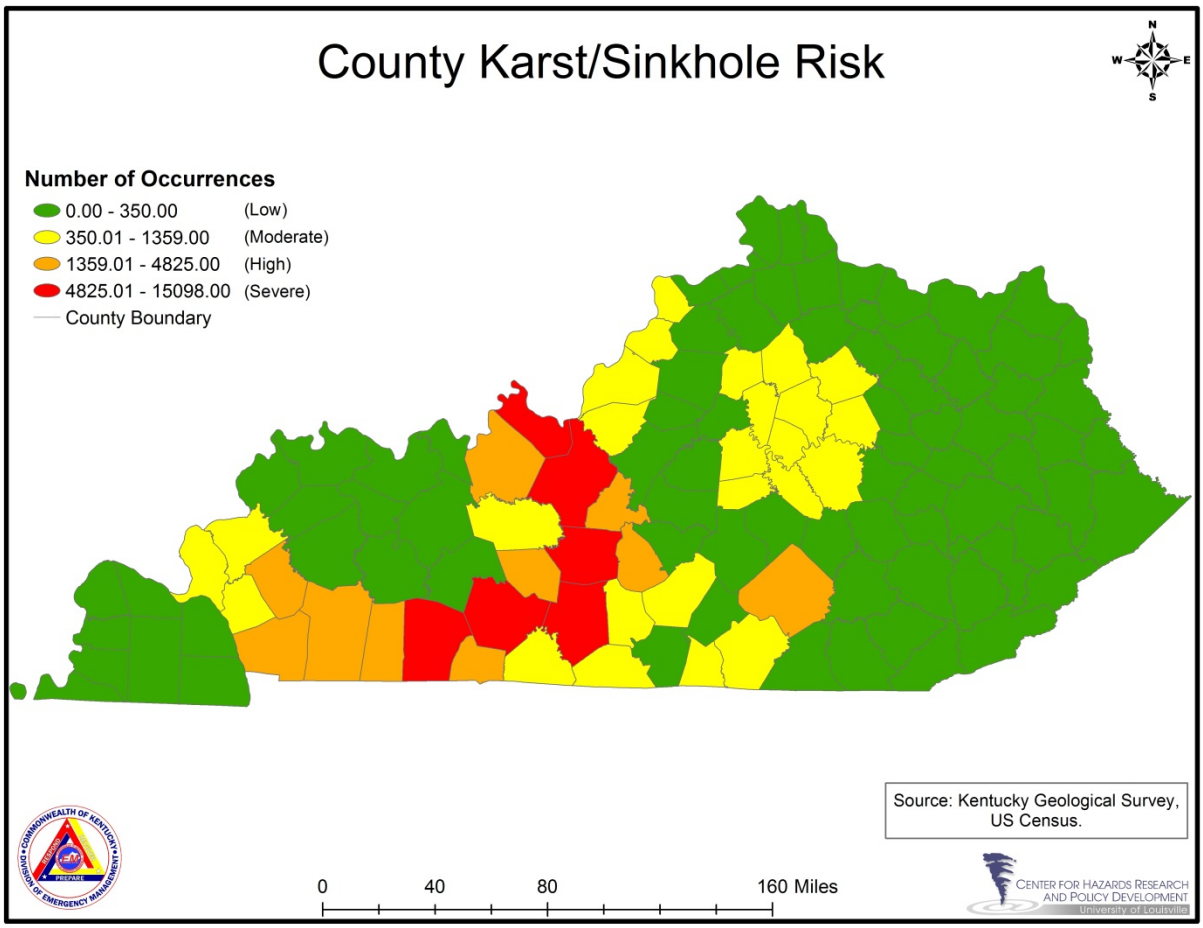
The Grid-Level Risk Assessment Model should be used to identify specific areas of vulnerability located throughout Kentucky. This model provides 106,178 equal areas of comparison for the end users to assess hazard vulnerability. The best way to view and use this data is through a GIS viewer.

The following map displays the maps and components of the Karst/Sinkhole Vulnerability Score.



County-Level Risk Assessment Model

The Karst/Sinkhole County Risk Assessment Model was created computing a count of the number of sinkholes per county. This data was then joined to a county map for display as seen below.



The County-Level Risk Assessment Model should be used to compare county-level risk. This data depicts which counties are experiencing the most occurrences of sinkholes comparatively across Kentucky.

Mine/Land Subsidence

Identifying Hazards: Mine/Land Subsidence

Description

Land subsidence is a gradual settling or sudden sinking of the Earth's surface owing to subsurface movement of earth materials. Subsidence is a global problem and, in the United States, more than 17,000 square miles in 45 States, an area roughly the size of New Hampshire and Vermont combined, have been directly affected by subsidence. The principal causes are aquifer-system compaction, drainage of organic soils, underground mining, hydrocompaction, natural compaction, sinkholes, and thawing permafrost. Three distinct processes account for most of the water-related subsidence--compaction of aquifer systems, drainage and subsequent oxidation of organic soils, and dissolution and collapse of susceptible rocks.

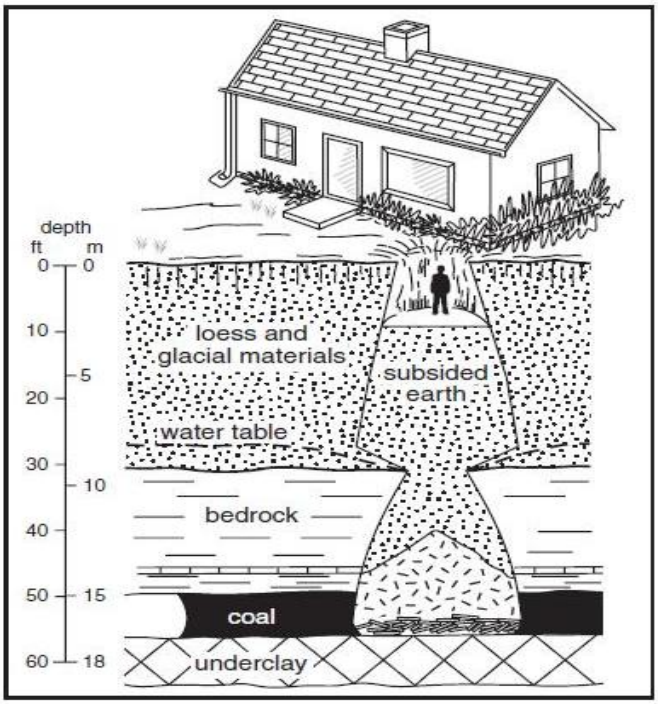
General forms of land subsidence most often occur when large amounts of ground water have been withdrawn from certain types of rocks, such as fine-grained sediments. The rock compacts as voids form in place of the water. As more water is withdrawn, the rock falls in on itself. The occurrence of land subsidence may easily go unnoticed because it generally covers large areas and develops gradually.

Mine subsidence, a more specific type of land subsidence, can be defined as *movement of the ground surface as a result of readjustments of the overburden due to collapse or failure of underground mine workings*. Surface subsidence features usually take the form of either very large sinkholes referred to as pits or troughs.

Mine subsidence is most often associated with coal mines, but can also be attributed to the mining of other minerals such as lead and zinc. Subsidence caused by these prior operations can wreak havoc on structures, causing large cracks in foundations, walls, and ceilings, separation of chimneys, porches, and steps from the structure, and the breakage of water, sewer, and gas lines. Popping and cracking can be heard as the structure settles and often, windows will break as well while settlement occurs. Many of the problems may occur simultaneously.

Types

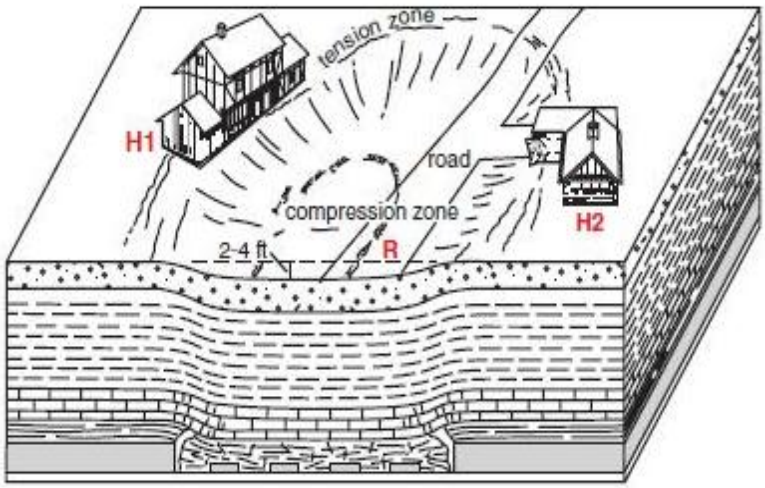
As depicted in the following drawing, pit subsidence occurs most commonly over mines that are considered fairly shallow, at less than 100 feet deep. Collapse of a mine roof causes a pit on the surface that generally ranges in depth from six (6) to eight (8) feet and in diameter from two (2) to 40 feet, although on average, a pit will reach less than 16 feet across. Just as with new sinkholes, new pits have steep sidewalls that present an added danger to humans and wildlife in the area. Pit subsidence usually occurs more rapidly than trough subsidence.



PIT SUBSIDENCE

(Source: Wildanger et al, 1980)

As shown below, trough subsidence forms gentle, more linear depressions over a broad area and most often is caused by the disintegration or collapse of coal pillars, resulting in depressions that sometime span the entire length of a whole mine panel which may be up to several hundred feet long and a few hundred feet wide.

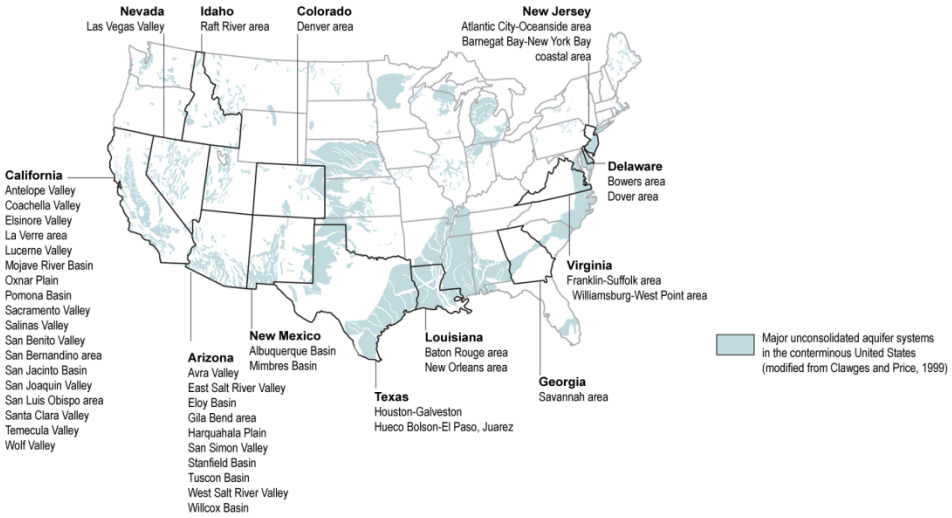


TROUGH SUBSIDENCE

(Source: Illinois State Geological Survey (ISGS), 2006.)

Facts

- Nationwide, the most common cause of land subsidence (over 80%) is the extraction of water from underground aquifers.



(Areas where subsidence has been attributed to the compaction of aquifer systems caused by ground-water pumpage. Source: USGS, http://water.usgs.gov/ogw/pubs/fs00165/)

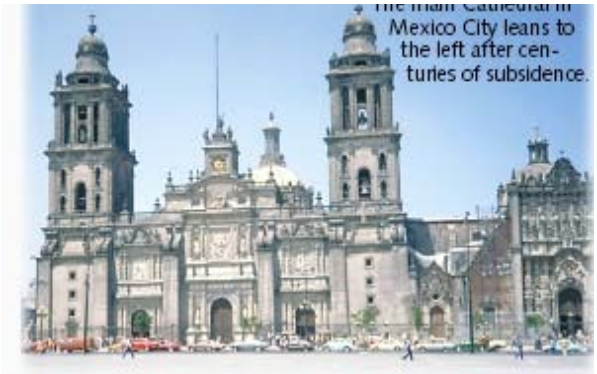
- Mine subsidence is controlled by a number of factors, including:
  - Height of mined-out area
  - Width of unsupported mine roof
  - Thickness of overburden
  - Competency of bedrock
  - Pillar dimensions
  - Hydrology
  - Fractures and joints
  - Time
- Between 1995 and 2001, the Ohio Department of Transportation spent $26.6 million to repair mine subsidence damage on eight (8) highway projects.
- An estimated 320,000 housing units in the state of Illinois are built over or adjacent to underground mines.
- In the state of Kentucky, the room-and-pillar mining technique responsible for most trough subsidence is still the most commonly used practice for underground mining.

Impacts

In areas where mining occurs, it is strongly suggested that homeowners acquire insurance coverage which specifically addresses mine subsidence. In some states property owners are required by law to possess such policies. It is for these reasons, annual out-of-pocket expenses for private landowners is much lower than that of other natural disasters, such as landslides.

Early longwall mine. Source: ISGS, 2006

Land subsidence, in general, is experienced throughout the country and the world each year, even in areas where mining isn't prevalent. The Jefferson Memorial in Washington, DC has been a sight of significant subsidence, as has the main Cathedral in Mexico City and the 15th century Inca settlement of Machu Picchu, in the Peruvian Andes.



Source: USGS, 2009

In terms of loss of human life, the potential risk associated with Mine/Land Subsidence is substantially lower than it is for other disasters such as tornadoes, earthquakes, and landslides, but it is important to keep in mind that the ground at the bottom of a pit or trough is often times not as stable as it appears. It is also important to ensure that the public is aware of the risks associated with inappropriate accessing of mine shafts, particularly those that have been abandoned for a number of years.

Profiling Hazards: Mine/Land Subsidence

MINE/LAND SUBSIDENCE PROFILE RISK TABLE	
Period of occurrence:	At any time. Chance of occurrence increases after heavy rainfall, snow melt, or construction and mining activity.
Number of events: (1981-2013)	133*
Annual Rate of Occurrence:	4.16
Warning time:	Warning times vary greatly and are often dependent upon inspection for weaknesses in rock and soil. Most subsidence problems move slowly and cause damage gradually; however some events can move very quickly.
Potential impacts:	Economic losses such as decreased land values, agribusiness losses, disruption of utility and transportation systems, and costs for any litigation. May cause geological movement, causing infrastructure damages ranging from minimal to severe. May cause injury or death and shut down critical facilities for days or weeks.
Recorded losses:	$5,550,000*
Annualized Loss:	$173,438
Extent[5]:	Deaths: Multiple per year Damage/Reclamation Costs: $13.5-14 M in mine reclamation grant dollars over a 3 year period: Some go up into the millions of dollars

*Data captured the Division of Abandoned Mine Lands (AML)

In Kentucky, land subsidence is often used interchangeably with mine subsidence, as abandoned subterranean mining operations are the most common cause of subsidence events. For this reason, subsidence is most likely to occur in the Eastern and Western coalfield regions of the state.

Kentucky coal mining has suffered more roof fall accidents and production loss due to roof collapse problems than any other coal-producing state. The geologic factors related to roof collapse commonly include faults, fractures, weak and disturbed roof strata, and rider coals (thin coals separated from the main coal seam, often by a weak shale-ridden zone).

[5] Mine/Land Subsidence presents a tricky interpretation of "extent": It is arbitrary to compare a mine/land subsidence event to some "standard," whether scale-based or historically-based. The danger, the extent to how severe the havoc wrought from a mine/land subsidence event is based upon the individual and mutually exclusive characteristics of abandoned the mine/land. It is arbitrary to compare events across mines as one would compare, say, tornadoes across a certain geographical area. An abandoned mine could be 164 feet (50 meters) or over two (2) miles (approximately 12,801 feet or 3,902 meters – the Anglo Gold Ashanti's Tautona mine) down; the extent, the absolute severity of the physical havoc to be wrought from any mine/land subsidence event is death to those experiencing the event. Otherwise, a small abandoned mine will produce a proportional "extent" in terms of physical characteristics of the damage. A large abandoned mine will produce similar proportional "extent" in terms of physical characteristics of the damage.

Although the greatest number of abandoned mines runs in a belt through western Pennsylvania, eastern Kentucky, and central West Virginia, data on past occurrences isn't maintained in any single database for the Commonwealth of Kentucky.

Dozens of people of all ages die each year in accidents that occur in and around abandoned mines, with many of these deaths occurring in Kentucky. Victims of such accidents have encountered deadly odorless gasses, fallen down holes that open under their weight, drowned in near-freezing pools of water at the bottom of shafts, and have been buried in unpredictable cave-ins.

Each year Kentucky receives an Annual Abandoned Mine Land (AML) Grant with a three year lifespan that totals approximately $13.5 - 14 million. With this funding an average of 25 to 35 reclamation projects are performed each year and costs for the projects vary from a few thousand to several million dollars.

The goal of these AML grants is to mitigate the hazards associated with subsidence and abandoned mines including landslides, dangerous highwalls, mine drainage, sedimentation and flooding, dangerous impoundments, open portals and shafts, open pits, dangerous piles and embankments, refuse piles, refuse fires, mine fires, hazardous facilities and equipment, and polluted water including surface and ground water pollution.

Assessing Vulnerability by Jurisdiction: Mine/Land Subsidence

Grid-Level Risk Assessment Model

Mine/Land Subsidence Vulnerability Score = Exposure Score + Hazard Score

Assessing Kentucky's vulnerability to Mine/Land Subsidence was determined through first calculating the Mine/Land Subsidence Hazard Score. The Mine/Land Subsidence Hazard Score was calculated by studying two (2) sources of data. The first layer used to create the Mine/Land Subsidence Hazard Score was derived from a GIS mined out layer from KGS. The mined out layer displays a geo-referenced data layer that depicts where mining operations have been. To analyze Kentucky's risk to Mine/Land Subsidence, the mined out layer was overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based on the percent of the area the mined out layer covered within each grid. This percentage of area affected by the mapped mined out areas was then calculated and scored 0-1 to develop 50% of the Mine/Land Subsidence Hazard Score.

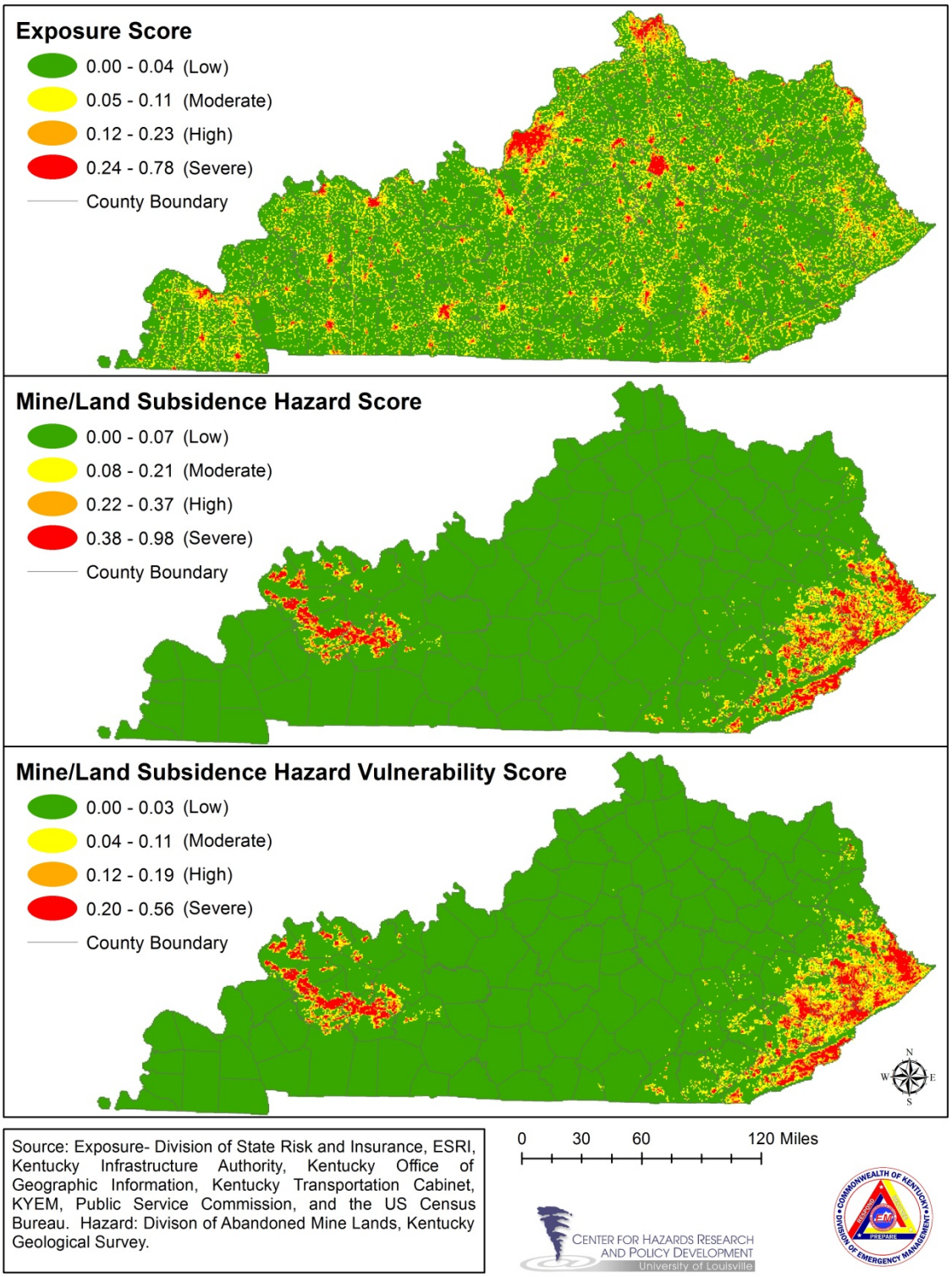
The next step was determined by calculating the number of areas AML has mitigated. This data displayed where concentrations of mine subsidence have occurred, thus producing areas of risk. The AML mitigation layer displays a geo-referenced data layer that depicts where mine subsidence has been mitigated. To analyze Kentucky's risk to Mine/Land Subsidence, the mine subsidence layer was overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based the total number of projects that have occurred within each grid. The total number was then calculated for each grid and scored 0-1 to develop 50% of the Mine/Land Subsidence Hazard Score.

The Mine/Land Subsidence Hazard Score was then calculated by adding the two (2) scores together and scored 0-1. It is important to note if the Mine/Land Subsidence Hazard Score inputs equaled 0, then the Mine/Land Subsidence Hazard Vulnerability Score equaled 0.

Finally, the Mine/Land Subsidence Vulnerability Score was calculated for each 1 KM MGRS grid by adding each grid's Exposure Score by its Mine/Land Subsidence Hazard Score and then scored 0-1. Once the final Mine/Land Subsidence Vulnerability Scores were calculated the composite scores were broken into four (4) categories, using the Natural Breaks classification system (1. Low, 2. Moderate, 3. High, 4. Severe) which demonstrates different levels of vulnerability displayed on the map.

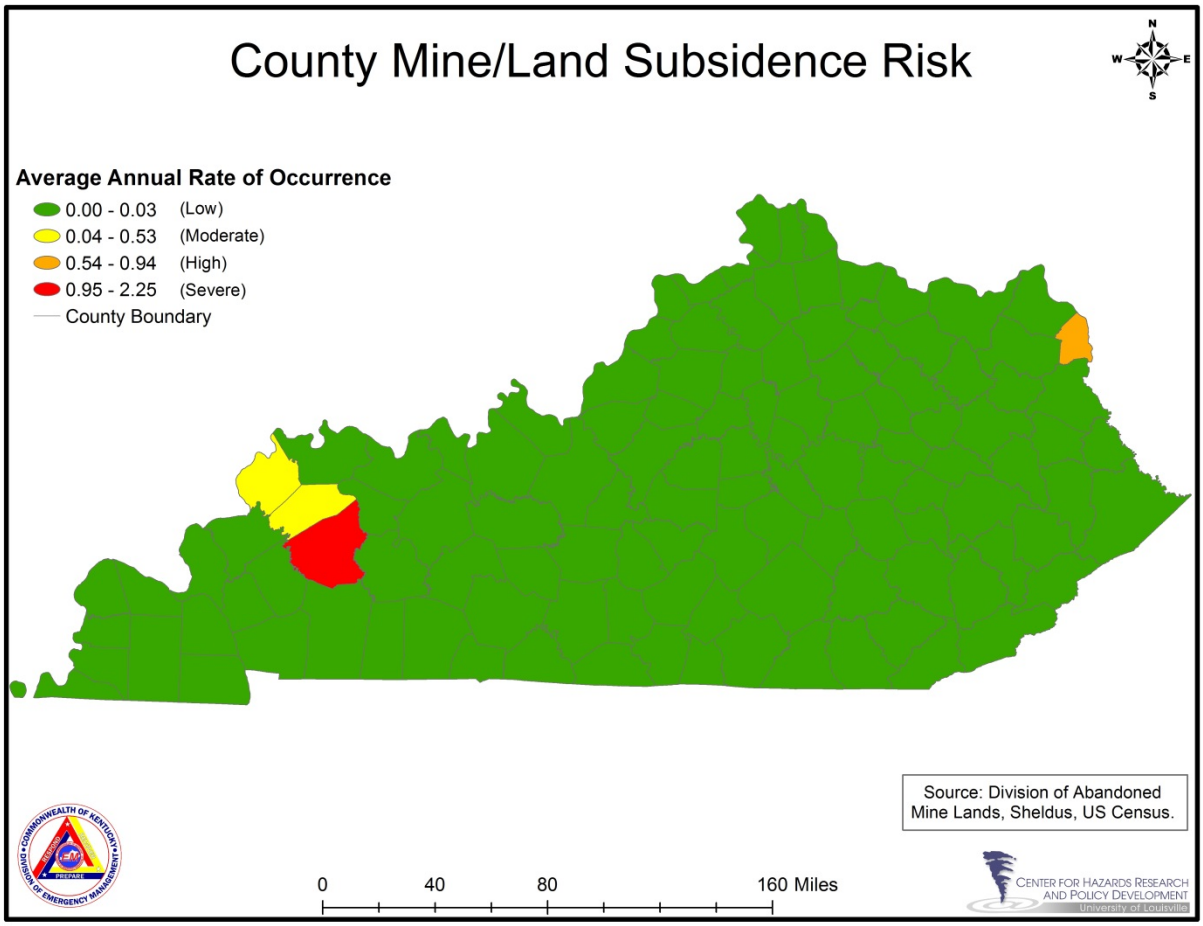
The Grid-Level Risk Assessment Model should be used to identify specific areas of vulnerability located throughout Kentucky. This model provides 106,178 equal areas of comparison for the end users to assess hazard vulnerability. The best way to view and use this data is through a GIS viewer.

The following map displays the maps and components of the Mine/Land Subsidence Vulnerability Score.



County-Level Risk Assessment Model

The Mine/Land Subsidence County Risk Assessment Model was created using the Mine/Land Subsidence Annual Rate of Occurrence data for each county. The annual rate of occurrence is calculated by dividing the range of years the data has been captured by each county's total number of occurrences (See ***Appendix 3-2*** "Hazard Average Annualized Loss"). This data was then joined to a county map for display as seen below.



The County-Level Risk Assessment Model should be used to compare county level risk. This data depicts which counties are experiencing the most occurrences of mine subsidence comparatively across Kentucky.

Landslide

Identifying Hazards: Landslide

Description

Landslides occur when masses of rock, earth, or debris move down a slope. Landslides may be very small or very large, and can move at slow to very high speeds. Many landslides have been occurring over the same terrain since prehistoric times. They are activated by storms and fires and by human modification of the land. New landslides occur as a result of rainstorms, earthquakes, volcanic eruptions, and various human activities.

Mudflows or debris flows are rivers of rock, earth, and other debris saturated with water. They develop when water rapidly accumulates in the ground, such as during heavy rainfall or rapid snowmelt, changing the earth into a flowing river of mud or "slurry." A slurry can flow rapidly down slopes or through channels, and can strike with little or no warning at avalanche speeds. A slurry can travel several miles from its source, growing in size as it picks up trees, cars, and other materials along the way.

Most of the landslide damage does not occur in rugged mountain country. Most losses from landslides and soil creep occur in cities developed on gently sloping hillsides. Although a landslide may occur almost anywhere, from man-made slopes to natural, pristine ground, most slides often occur in areas that have experienced sliding in the past. All landslides are triggered by similar causes. These can be weaknesses in the rock and soil, earthquake activity, the occurrence of heavy rainfall or snowmelt, or construction activity changing some critical aspect of the geological environment. Landslides that occur following periods of heavy rain or rapid snow melt worsen the accompanying effects of flooding.

Landslides pose a hazard to nearly every state in the country by causing $2 billion in damages and 25 to 50 deaths a year. There is a concentration of losses in the Appalachian, Rocky Mountain and Pacific Coast regions. It has been estimated that about 40 percent of the U.S. population has been exposed to the direct and indirect effects of landslides.

Public and private economic losses from landslides include not only the direct costs of replacing and repairing damaged facilities, but also the indirect cost associated with lost productivity, disruption of utility and transportation systems, reduced property values, and costs for any litigation. Some indirect costs are difficult to evaluate, thus estimates are usually conservative or simply ignored. If indirect costs were realistically determined, they likely would exceed direct costs.

Much of the economic loss is borne by federal, state, and local agencies responsible for disaster assistance, flood insurance, and highway maintenance and repair. Private

costs involve mainly damage to land and infrastructures. A severe landslide can result in financial ruin for the property owners because landslide insurance (except for debris flow coverage) or other means of spreading the costs of damage are unavailable.

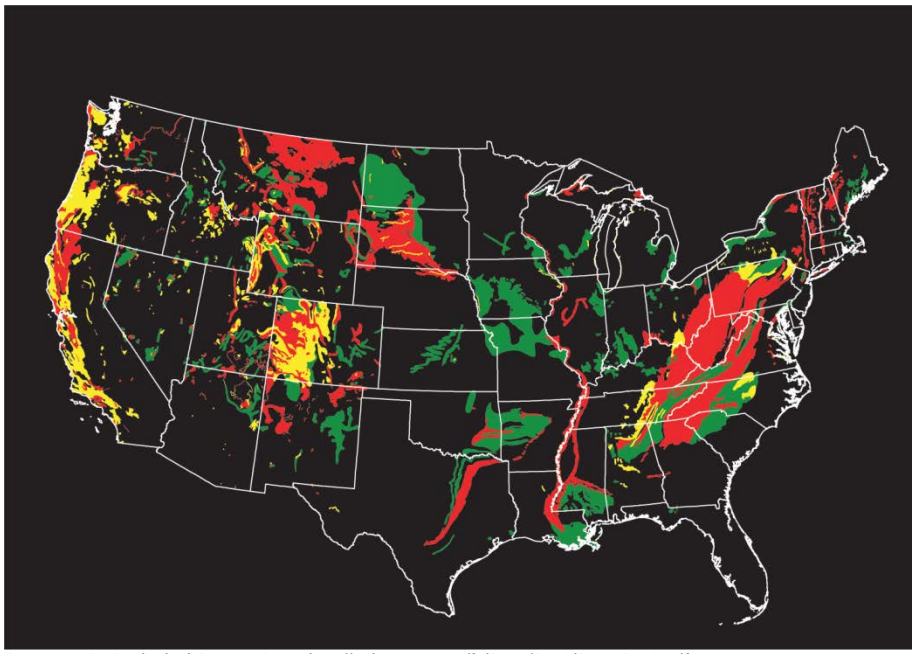
Types

- *Slides* of soil or rock involve downward displacement along one of more failure surfaces. The material from the slide may be broken into a number of pieces or remain a single, intact mass. Sliding can be rotational, where movement involves turning about a specific point. Sliding can be translational, where movement is down slope on a path roughly parallel to the failure surface. The most common example of a rotational slide is a slump, which has a strong, backward rotational component and a curved, upwardly-concave failure surface.
- *Flows* are characterized by shear strains distributed throughout the mass of material. They are distinguished from slides by high water content and distribution of velocities resembling that of viscous fluids. Debris flows are common occurrences in much of North America. These flows are a form of rapid movement in which loose soils, rocks, and organic matter, combined with air and water, form slurry that flows downslope. The term “debris avalanche” describes a variety of very rapid to extremely rapid debris flows associated with volcanic hazards. Mudflows are flows of fine-grained materials, such as sand, silt, or clay, with high water content. A subcategory of debris flows, mudflows contains less than 50 percent gravel.
- *Lateral spreads* are characterized by large elements of distributed, lateral displacement of materials. They occur in rock, but the process is not well-documented and the movement rates are very slow. Lateral spreads can occur in fine-grained, sensitive soils such as quick clays, particularly if remolded or disturbed by construction and grading. Loose, granular soils commonly produce lateral spread through liquefaction. Liquefaction can occur spontaneously, presumably because of changes in pore-water pressures, or in response to vibrations such as those produced by strong earthquakes.
- *Falls and Topples*. Falls occur when masses of rock or other material detach from a steep slope or cliff and descend by free fall, rolling, or bouncing. These movements are rapid to extremely rapid and are commonly triggered by earthquakes. Topples consist of forward rotation of rocks or other materials about a pivot point on a hill slope. Toppling may culminate in abrupt falling, sliding, or bouncing, but the movement is tilting without resulting in collapse. Data on rates of movement and control measures for topples is sparse.

Facts

- Steep slopes are more susceptible to landslides and should be avoided when choosing a building site.
- Slope stability decreases as water moves into the soil. Springs, seeps, roof runoff, gutter down spouts, septic systems, and site grading that cause ponding or runoff are sources of water that often contribute to landslides.
- Changing the natural slope by creating a level area where none previously existed adds weight and increases the chance of a landslide.
- Poor site selection for roads and driveways.
- Improper placement of fill material.
- Removal of trees and other vegetation. Plants, especially trees, help remove water and stabilize the soil with their extensive root systems.

USGS United States Landslide Susceptibility Map



Source: U.S. Geological Survey. 2005. http://pubs.usgs.gov/fs/2005/3156/2005-3156.pdf

Profiling Hazards: Landslide

LANDSLIDE PROFILE RISK TABLE	
Period of occurrence:	At any time. Chance of occurrence increases after heavy rainfall, snow melt, or construction and mining activities.
Number of events: (1975-2013)	1,393*
Annual Rate of Occurrence:	36.66
Warning time:	Days to months, depends on inspection for weakness in rock and soil.
Potential impacts:	Economic losses such as decreased land values, infrastructure damage, and agro-business losses. May cause minimal to severe property damage and destruction.
Recorded losses:	$28,365,706*
Annualized Loss:	$746,466
Extent:	Damage: $2 million to repair annually Location: Statewide Data Currently Unavailable related to a physical standard by which to compare landslide hazard events[6]

*Data captured from the Kentucky Geological Survey

[6] The 2010 Update of the Commonwealth of Kentucky's hazard mitigation plan makes no mention of and thusly provides no data or historical context from which the "extent" of landslides within Kentucky can be compared. Further, a thorough review of literature provides ample data regarding damages resulting from landslides, but scant concerning physical descriptions of landslides within Kentucky. However, within Kentucky, we do know this: The massive 1811-1812 New Madrid Earthquake series (which remains the most powerful set of earthquakes to strike the eastern United States in recorded history) struck within Kentucky. Some oft-cited reports written in the late 19th, early 20th century allude to equally massive landslides being the result of the 1811-1812 New Madrid Earthquakes. Some of these reports even describe the physical characteristics of the resulting landslides with rather pastoral prose [e.g. Fuller 1912]. That the 1811-1812 New Madrid Earthquakes caused these landslides described so poetically has been confirmed by Jibson [1985] (and Jibson, Keefer 1988). Thus, for inexact descriptions of how bad (with what magnitude) a landslide in Kentucky can become, see the following:

- Jibson, R.W. and D.K. Keefer. [1988]. "Landslides Triggered by Earthquakes in the Central Mississippi Valley, Tennessee and Kentucky." *United States Geological Survery (USGS) Professional Paper 1336-C*. DC: United States Government Printing Office.
- Jibson, R.W. [1985]. "Landslides Caused by the 1811-1812 New Madrid Earthquakes." *Unpublished Doctoral Dissertation for Stanford University Department of Geology*.
- Penick, J.L. [1981]. *The New Madrid Earthquakes (Revised Edition)*. Columbia, MO: University of Missouri Press.
- Fuller, M.L. [1912]. "The New Madrid Earthquake." *United States Geological Survey (USGS) Bulletin 494*.
- Safford, J.M. [1869]. *Geology of Tennessee*. Nashville, TN: S.C. Mercer.
- Owen, D.D. [1856]. *Report of the Geological Survey in Kentucky, Made During the Years 1854 and 1855*. Frankfort, KY: A.G. Hodges State Printer.

Landslide-related **Presidential Disaster Declarations 2005-2013**																	
Disaster Declaration	Incident Period	Individual Assistance Applications*	Amount Disbursed*	Total Public Assistance Grants**	Dam Failure	Drought	Earthquake	Extreme Temp.	Flood	Hailstorm	Karst/Sinkhole	Land/Mine	Landslide	Severe Storm	Severe Winter	Tornado	Forest Fire
DR-1925	July 17-30, 2010	2,548	$ 10,602,929	$ 6,372,211					x				x	x			
DR-1912	May 1, 2010	7,343	$ 20,784,629	$ 22,522,805					x				x	x			
DR-1841	May 3-20, 2009	5,543	$ 15,117,446	$ 34,825,014					x				x	x		x	
DR-1757	April 3-4, 2008	not requested	not requested	$ 3,499,938					x				x	x		x	

*Source: KY Division of Emergency Management, Recovery Branch. IA Disaster Summary by County.

**Source: FEMA.gov

Kentucky's landslides have occurred in all regions of the state, mostly in the Ohio River Valley, the Knobs, the Outer Bluegrass, and the Eastern Kentucky Coal Field. Since the early 1970's the Kentucky Transportation Cabinet and the Kentucky Transportation Center has received reports of approximately 3,000 landslides. Costs for repair of landslides exceed $2 million annually. Thousands of slides are unrelated to transportation, however, and many are unreported. These also pose significant hazards to people and infrastructure. The chart below demonstrates that landslide has been recorded in association with four presidentially declared disasters from 2008 to 2010.

Pike County, Kentucky 2010

Landslide problems in Kentucky are usually related to certain rock formations on yield soils which are unstable on moderate to steep slopes. Often, slopes are cut into or over-steeped to create additional level land for development. For example, a landslide which occurred on a connector road from Alexandria to Ashland Highway in northern Kentucky cost the state millions of dollars to repair; and an effort to create several acres of level land for a shopping complex in Laurel County triggered a landslide which created damage to a subdivision upslope from the complex and threatened a major highway below.

Landslide problems can be compounded when unrecognized ancient slides are excavated during construction. The most spectacular and well-documented reactivation of an ancient landslide in Kentucky occurred during construction of U.S. Highway 119 between Pineville and Harlan. When the contractor inadvertently excavated through an ancient landslide in this area, several slope failures were triggered. The problems caused by these failures delayed completion of the highway, significantly increased costs, and caused time-consuming and expensive ongoing maintenance for the Kentucky Transportation Cabinet.

Similarly, part of the business district of Hickman was destroyed when a contractor for the U.S. Army Corps of Engineers, in an attempt to construct a ground water cutoff wall in front of the existing floodwall, cut through an old landslide which was a resulted of the 1811-1812 earthquakes. Many homes have also been damaged or destroyed in eastern and southeastern Kentucky because they were constructed on unstable geologic formations, or because of a combination of unstable soil and rock and the subsidence of abandoned underground mines.

Below is a description of landslide events resulting from the four previously listed presidentially declared disasters:

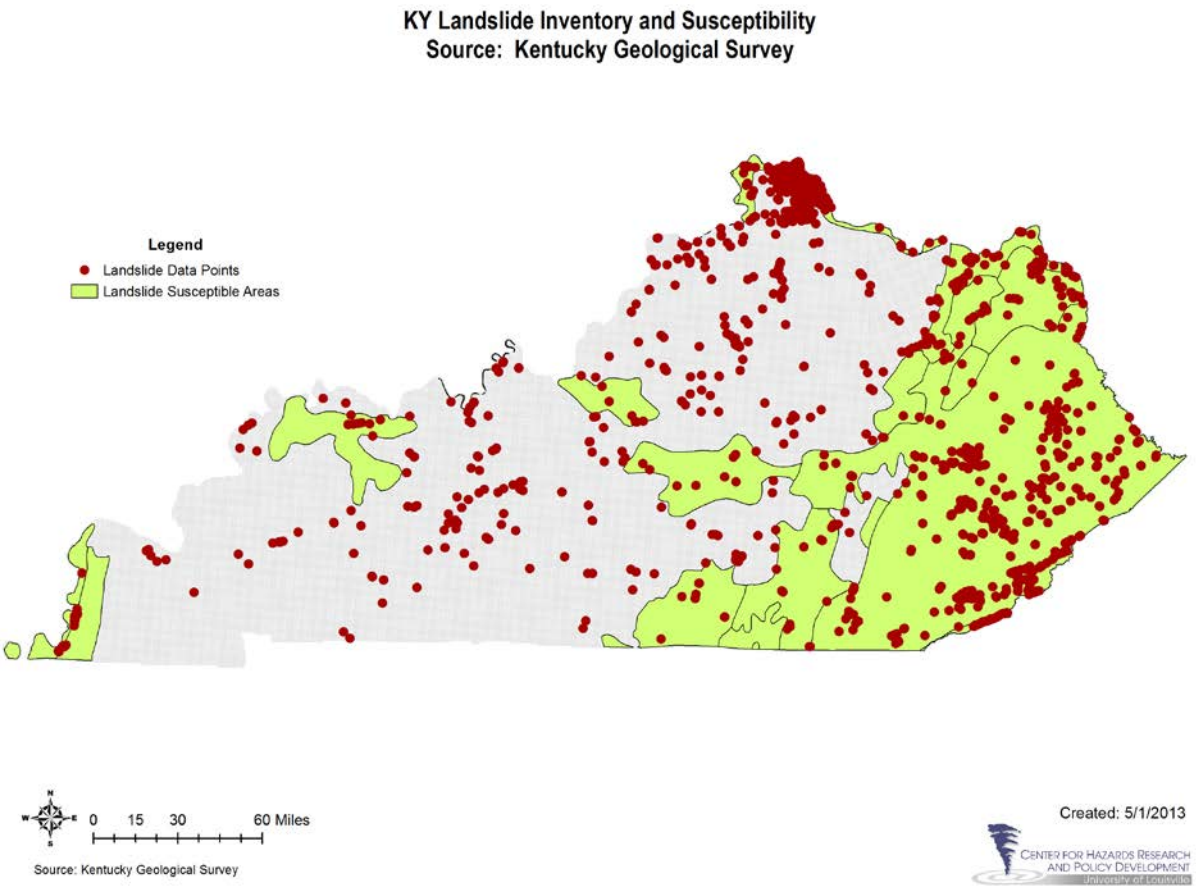
- **July 17-30, 2010 (DR-1925):** Over the period of July 17-30 severe storms caused widespread tree and power damage, flooding and mudslides, particularly in Pike County. Up to 8 inches of rain fell in a short period of time, prompting emergency evacuations and rescues. Approximately 200 homes were damaged or destroyed by the flooding and mudslides.

- **May 1, 2010 (DR-1912):** Multiple lines and clusters of intense showers and strong to severe thunderstorms brought a variety of severe weather to eastern Kentucky. During the overnight hours a large area of intense showers and thunderstorms dumped anywhere from 2 to over 7 inches of rainfall.
    - Estill County. Heavy rain caused a mudslide in the Hargett area on Route 89. Brown Ridge Road and Highway 89 north of Estill High School were closed due to mudslides.
    - Powell County. A report was received of a hillside collapsing into the back of a house on Skinner Branch Road in Clay City.

- **May 3-20, 2009 (DR-1841):** This major disaster declaration was due to severe storms, heavy rain, flooding, high winds, tornadoes, and mudslides in 22 counties. Starting on May 3, 2009, strong storms moved across the central and eastern parts of the Commonwealth resulting in the loss of life and private property and road closures. There were over half a million citizens impacted by this event.

- **April 3-4, 2008 (DR-1757):** Kentucky was impacted by severe thunderstorms which produced tornadoes, floods, flash flood, hail, mudslides, and landslides. This line of severe weather resulted in loss of life and personal injury, power outages, downed trees, road closures, and widespread damage. Records show that four to six inches of rain fell in a 24-hour period, with some locally higher observations exceeding eight inches.

In addition to the above mudslide occurrences resulting from four disaster declarations, the Kentucky Geological Survey (KGS) has recorded data points of landslide hazards and areas susceptible to landslides. Landslide locations come from KGS research, published maps, state and local government agencies, the public, and the media. The purpose is to provide and overall view of landslide hazards across the state. Below is a map that demonstrates landslide data points and susceptibility:



Assessing Vulnerability by Jurisdiction: Landslide

Grid-Level Risk Assessment Model

Landslide Vulnerability Score = Exposure Score + Hazard Score

Assessing Kentucky's vulnerability to Landslide was determined through first calculating the Landslide Hazard Score. The Landslide Hazard Score was calculated by studying two (2) sources of data. The first layer used to create the Landslide Hazard Score was derived from the USGS Landslide Overview GIS map layer. The landslide layer displays a geo-referenced data layer that depicts where landslide susceptibility is located throughout United States. To analyze Kentucky's risk to Landslide, the landslide layer was overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based on the percent of the area the landslide layer covered within each grid. This percentage of area affected by the landslide potential areas was then calculated and scored 0-1 to develop 50% of the Landslide Hazard Score.

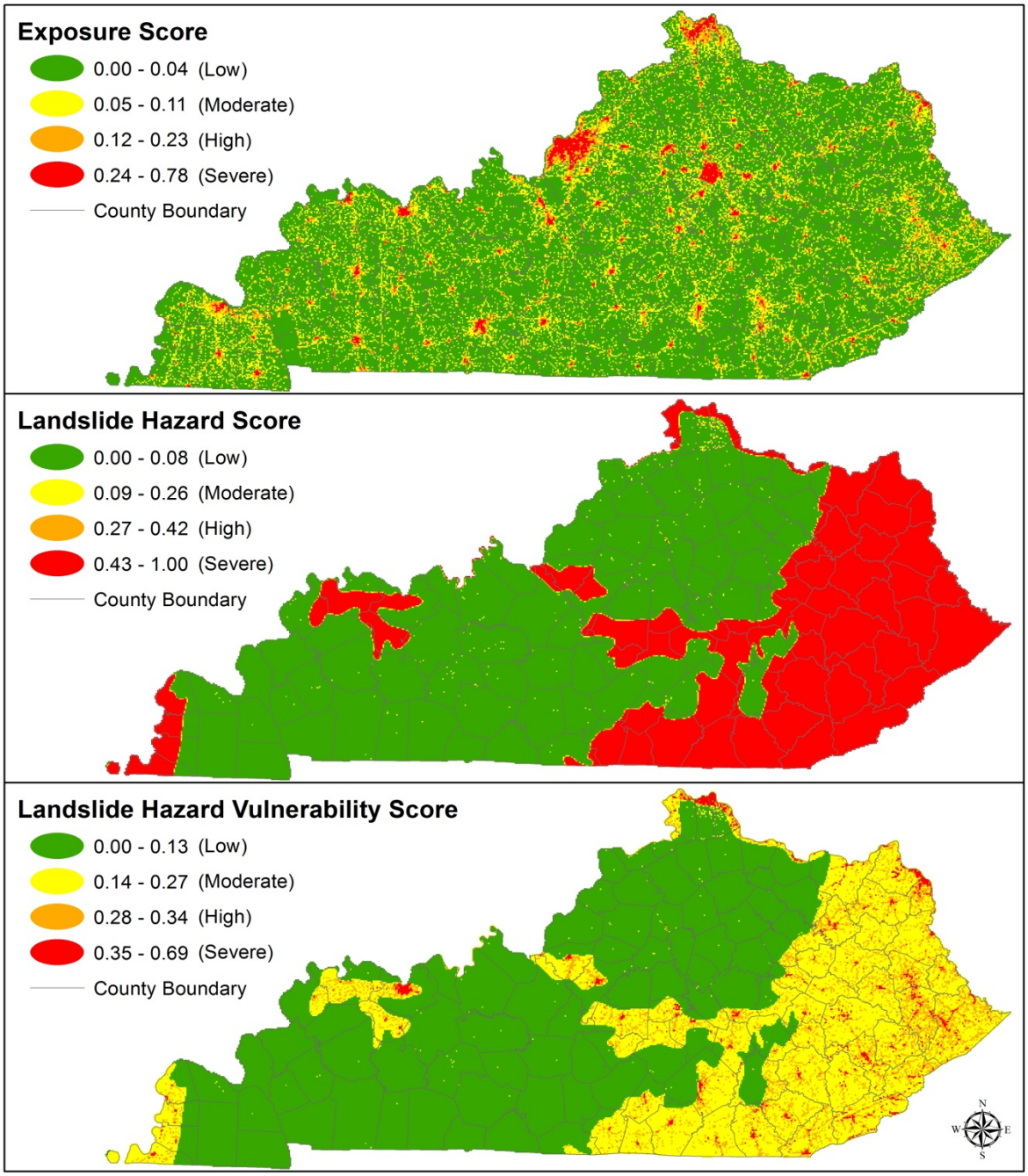
The next step was determined by calculating the number of landslide points. This point data acquired from KGS, displayed where concentrations of landslides have occurred, thus producing areas of risk. The KGS landslide point layer displays a geo-referenced data layer that depicts where landslides have been identified by KGS through a multitude of methods. To analyze Kentucky's risk to landslide, the KGS landslide point layer was overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based the total number of landslides that have occurred within each grid. The total number was then calculated for each grid and scored 0-1 to develop 50% of the Landslide Hazard Score.

The Landslide Hazard Score was then calculated by adding the two (2) scores together and scored 0-1. It is important to note if the Landslide Hazard Score inputs equaled 0, then the Landslide Hazard Vulnerability Score equaled 0.

Finally, the Landslide Vulnerability Score was calculated for each 1 KM MGRS grid by adding each grid's Exposure Score by its Landslide Hazard Score and then scored 0-1. Once the final Landslide Vulnerability Scores were calculated the composite scores were broken into four (4) categories, using the Natural Breaks classification system (1. Low, 2. Moderate, 3. High, and 4. Severe) which demonstrates different levels of vulnerability displayed on the map.

The Grid-Level Risk Assessment Model should be used to identify specific areas of vulnerability located throughout Kentucky. This model provides 106,178 equal areas of comparison for the end users to assess hazard vulnerability. The best way to view and use this data is through a GIS viewer.

The following map displays the maps and components of the Landslide Vulnerability Score.



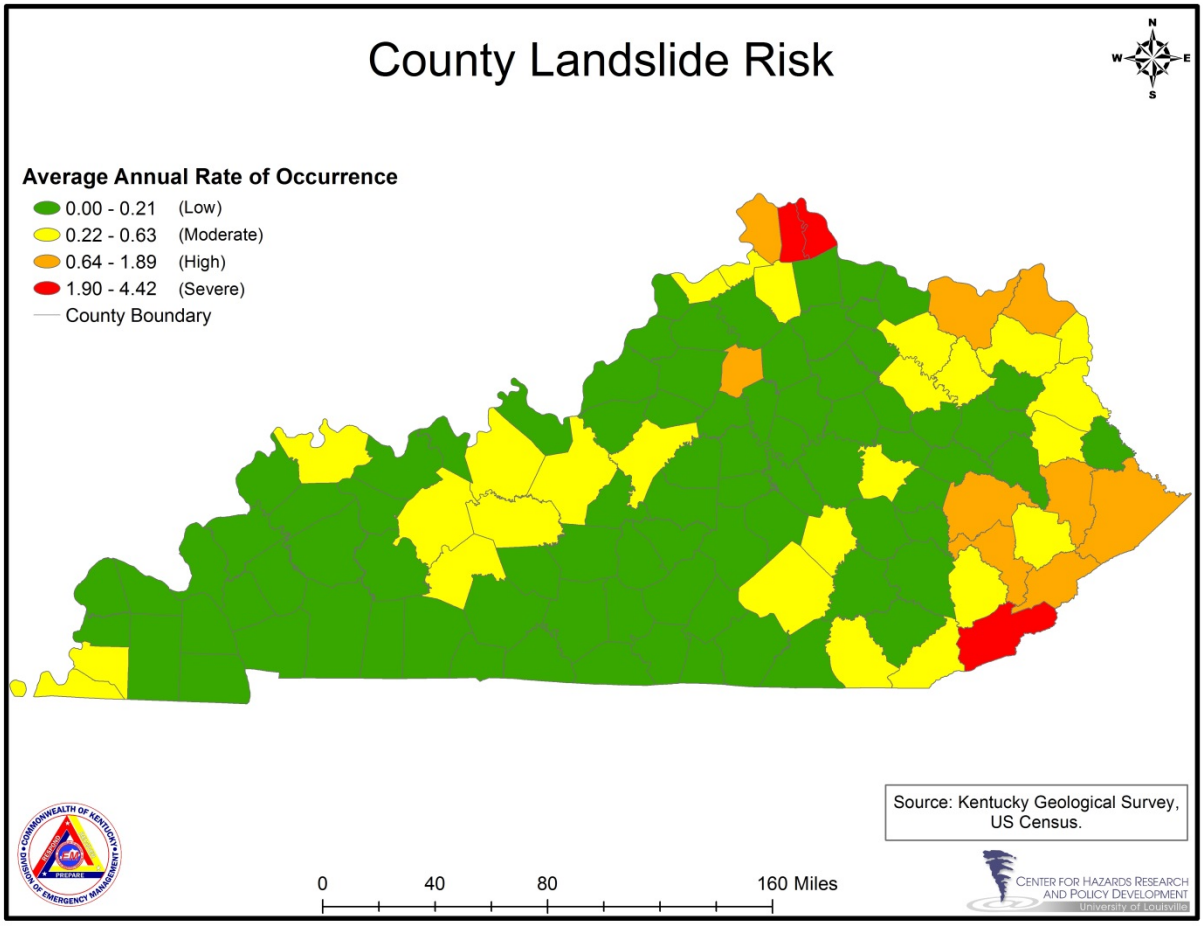
Source: Exposure- Division of State Risk and Insurance, ESRI, Kentucky Infrastructure Authority, Kentucky Office of Geographic Information, Kentucky Transportation Cabinet, KYEM, Public Service Commission, and the US Census Bureau. Hazard: Kentucky Geological Survey, USGS.

0 30 60 120 Miles

CENTER FOR HAZARDS RESEARCH AND POLICY DEVELOPMENT
University of Louisville

County-Level Risk Assessment Model

The Landslide County Risk Assessment Model was created using the Landslide Annual Rate of Occurrence data for each county. The annual rate of occurrence is calculated by dividing the range of years the data has been captured by each county's total number of occurrences (See ***Appendix 3-2*** "Hazard Average Annualized Loss"). This data was then joined to a county map for display as seen below.



The County-Level Risk Assessment Model should be used to compare county-level risk. This data depicts which counties are experiencing the most occurrences of landslides comparatively across Kentucky.

Hazard Category: NON-SEVERE WEATHER

Forest Fire

Identifying Hazards: Forest Fire

Description

A forest fire is any non-structural fire, other than a prescribed fire, that occurs in the wildland. The term encompasses fires previously called wildland fire, wildfires and prescribed natural fires. Though often a beneficial occurrence, fires are frequently suppressed by various agencies to prevent structural loss. Forest fire suppression is a management response that results in curtailment of fire spread and eliminates all identified threats from a particular fire. This suppression, however, eventually leads to more severe fires, as vegetation becomes denser.

Types

There are three different classes of forest fires:

- *Surface fires* are the most common type and burn along the floor of a forest, moving slowly and killing or damaging trees.
- *Ground fires* are usually started by lightning and burn on or below the forest floor.
- *Crown fires* spread rapidly by wind and move quickly by jumping along the tops of trees.
    - *Spotting* can be produced by crown fires as well as wind and topography conditions. Large burning embers are thrown ahead of the main fire. Once spotting begins, the fire will be very difficult to control.

The average forest fire kills most trees up to 3-4 inches in diameter, in the area burned. These trees represent approximately 20 years of growth. In the case of up-slope burning, under severe conditions, almost every tree is killed regardless of size or type. When the trees are burned and everything is killed, then the forest is slow to reestablish itself, because of the loss of these young seedlings, saplings, pole, and sawtimber trees.

Included in the destruction by fires are the leaf and other litter on the forest floor. This exposes the soil to erosive forces, allowing rainstorms to wear away the naked soil and wash silt and debris downhill, which will clog the streams and damage fertile farmlands in the valleys. Once the litter and humus (spongy layer of decaying matter) is destroyed, water flows more swiftly to the valleys and increases flood danger.

Other consequences of forest fires are the death of and loss of habitat for the forest's wildlife. Even when the adult animals escape, the young are left behind to perish. The heaviest wildlife lost is felt by game birds since they have ground nesting habits. Fish life also suffers as a result of the removal of stream shade and the loss of insect and plant food is destroyed by silt and lye from wood ashes washed down from burned hillsides.

Forest Fire Fuel Categories

- *Light* fuels such as shrubs, grasses, leaves, and pine needles (any fuel having a diameter of one-half inch or less) burn rapidly and are quickly ignited because they are surrounded by plenty of oxygen. Fires in light fuels spread rapidly but burn out quickly, are easily extinguished, and fuel moisture changes more rapidly than in heavier fuels.
- *Heavy* fuels such as limbs, logs, and tree trunks (any fuel one-half inch or larger in diameter) warm more slowly than light fuels, and the interiors are exposed to oxygen only after the outer portion is burned.
- *Uniform* fuels include all of the fuels distributed continuously over an area. Areas containing a network of fuels that connect with each other to provide a continuous path for a fire to spread are included in this category.
- *Patchy* fuels include all fuels distributed unevenly over an area, or as areas of fuel with definite breaks or barriers present, such as patches of rock outcroppings, bare ground, swamps, or areas where the dominant type of fuel is much less combustible.
- *Ground* fuels are all of the combustible materials lying beneath the surface including deep duff, tree roots, rotten buried logs, and other organic material.
- *Surface* fuels are all of the combustible materials lying on or immediately above the ground, including needles or leaves, duff, grass, small deadwood, downed logs, stumps, large limbs, and low shrubs.
- *Aerial* fuels are all of the green and dead materials located in the upper canopy, including tree branches and crowns, snags, hanging moss, and tall shrubs.

Fuel Types

1. *Grass*. Found in most areas, but grass is more dominant as a fuel in desert and range areas where other types of fuel are less prevalent. It can become prevalent in the years after a fire in formerly timbered areas.
2. *Shrub (brush)*. Shrub is found throughout most areas of the U.S. Some examples of highly flammable shrub fuels are the palmetto/ gallberry in the Southeast, sagebrush in the Great Basin, and chaparral in the Southwest.
3. *Timber litter*. This type of fuel is most dominant in mountainous topography, especially in the Northwest.
4. *Logging slash*. This fuel is found throughout the country. It is the debris left after logging, pruning, thinning, or shrub-cutting operations. It may include logs, chunks, bark, branches, stumps, and broken understory trees or shrubs.

Fuel Characteristics

Fuel moisture is the amount of water in a fuel. This measurement is expressed as a percentage. The higher the percentage of moisture extant in the fuel, the greater the water within the fuel. How well a fuel will ignite and burn is dependent, to a large extent, on its moisture content. Dry fuels will ignite and burn much more easily than the same fuels when they are wet (contain a high moisture content). As a fuel's moisture content increases, the amount of heat required to ignite and burn that fuel also increases. Light fuels take on and lose moisture faster than heavier fuels. Wet fuels have high moisture content because of exposure to precipitation or high relative humidity, while dry fuels have low moisture content because of prolonged exposure to sunshine, dry winds, Severe Storm, or low relative humidity.

Facts

- Homeowners can do much to help save their homes from forest fires, such as constructing the roof and exterior structure of a dwelling with non-combustible or fire resistant materials such as tile, slate, sheet iron, aluminum, brick or stone.
- While it was U.S. policy for most of the 20th century to suppress forest fires, fires actually benefit the ecosystem. The effects of fire can retard or accelerate the natural development of plant communities, alter species diversity and change nutrient flows.
- More than 100 years of suppressing fires, combined with past land-use practices, have resulted in a heavy buildup of dead vegetation, dense stands of trees, a shift to species that have not evolved and adapted to fire, and occasionally an increase in non-native, fire-prone plants. Because of these conditions, today's fires tend to be larger, burn hotter, and spread farther and faster, making them more severe.
- Government scientists have also concluded that "fire severity has generally increased and fire frequency has generally decreased over the last 200 years. The primary causative factors behind fire regime changes are effective fire prevention and suppression strategies, selection and regeneration cutting, domestic livestock grazing, and the introduction of exotic plants."
- Scientific analysis of the 2000 fire season revealed that the vast majority of burned acres were located in previously logged and roaded areas, not in road-less or wilderness areas.
- The Endangered Species Act permits federal officials to take actions that might impact endangered species or their habitat during times of emergency, including forest fire emergencies. Water can be taken from a river without permission from wildlife agencies during emergencies.
- There is consensus in the scientific literature dealing with fire and forest management that forests in un-roaded, un-logged areas have the most fire resiliency and present a lower fire risk compared to other areas.

- The Congressional Research Service, in an August 2000 report analyzing the impact of the fires in 2000, concluded, "Timber harvesting removes the relatively large diameter wood that can be converted into wood products, but leaves behind the small material, especially twigs and needles. The concentration of these 'fine fuels' on the forest floor increases the rate of spread of wildfires."
- Fire ecologists and most forest scientists agree that long-term ecological restoration with careful fire reintroduction (not increased resource extraction or aggressive fire suppression) holds the best hope of preventing future large-scale severe forest fires in fire-dependent ecosystems of the interior West.
- Many species depend on fires to improve habitat, recycle nutrients and maintain diverse habitats.
- Humans, either through negligence, accident, or intentional arson, have caused approximately 90% of all forest fires in the last decade. Accidental and negligent acts include unattended campfires, sparks, burning debris, and irresponsibly discarded cigarettes. The remaining 10% of fires are mostly caused by lightning, but may also be caused by other acts of nature such as volcanic eruptions or earthquakes.

Profiling Hazards: Forest Fire

FOREST FIRE PROFILE RISK TABLE	
Period of occurrence:	Spring Forest Fire Hazard Season: Feb. 15 through April 30 Fall Forest Fire Hazard Season: Oct. 1 through Dec. 15
Number of events: (1997-2012)	22,467*
Annual Rate of Occurrence:	898.68
Warning time:	None, unless associated with drought
Potential impacts:	Utility damage and outages, infrastructure damage (transportation and communication systems), structural damage, fire, damaged or destroyed critical facilities, and hazardous material releases.
Recorded losses:	$41,250**
Annualized Loss:	$1,650
Extent (Scale):	Year: 2010 Scale: 54,577 acres burned

*Data captured from the Kentucky Division of Forestry**Data captured from SHELDUS 10.1

"Forests cover approximately 12 million acres of land in Kentucky, representing 47 percent of the state's land cover. The Cumberland Plateau and the Appalachians in the eastern part of the state account for 50 percent of the state's forest cover, with 25 contiguous counties having a forest cover percentage of greater than 75 percent.

There are two defined wildfire seasons in Kentucky: February 15-April 30 and October 1-December 15. These spring and fall seasons are separated by periods of higher moisture and colder, less conducive fire weather. Leaf drop in the fall from deciduous hardwood trees produces a thick litter layer in forested areas which rapidly carries expanding wildfires. Tall grasses across the state become very flammable in the fall and during periods of drought. Wildfire occurrence is possible outside of these defined fire seasons during any prolonged periods of drought. During these wildfire seasons, specific outdoor burning laws have been established to lessen the occurrence of damaging wildfires.

Kentucky Revised Statute 149.400 prohibits outdoor burning during these fire seasons between 6 am and 6 pm unless at a distance of at least 150 feet from woodlands or brushland. Kentucky averages 1,484 wildfires a year that burn 38,000 acres of private lands. During the past ten years, these wildfires have destroyed 270 homes, structures, and improvements valued at $4,145,216.00. However, during the same time frame, 7,129 homes and structures have been saved by wildland firefighters for a value of $332,018,580.00. In the past five years wildfires in Kentucky have also been attributed to the deaths of at least five citizens including one Kentucky Division of Forestry

firefighter. Based on a recent study conducted by the University of Kentucky and the Kentucky Division of Forestry (KDF), the loss in timber value over this ten year period exceeds $139,450,000.00 [Reeves and Stringer 2010[7]]. With such a clear threat to life, and property, identifying successful wildfire mitigation projects has become a priority for the state.

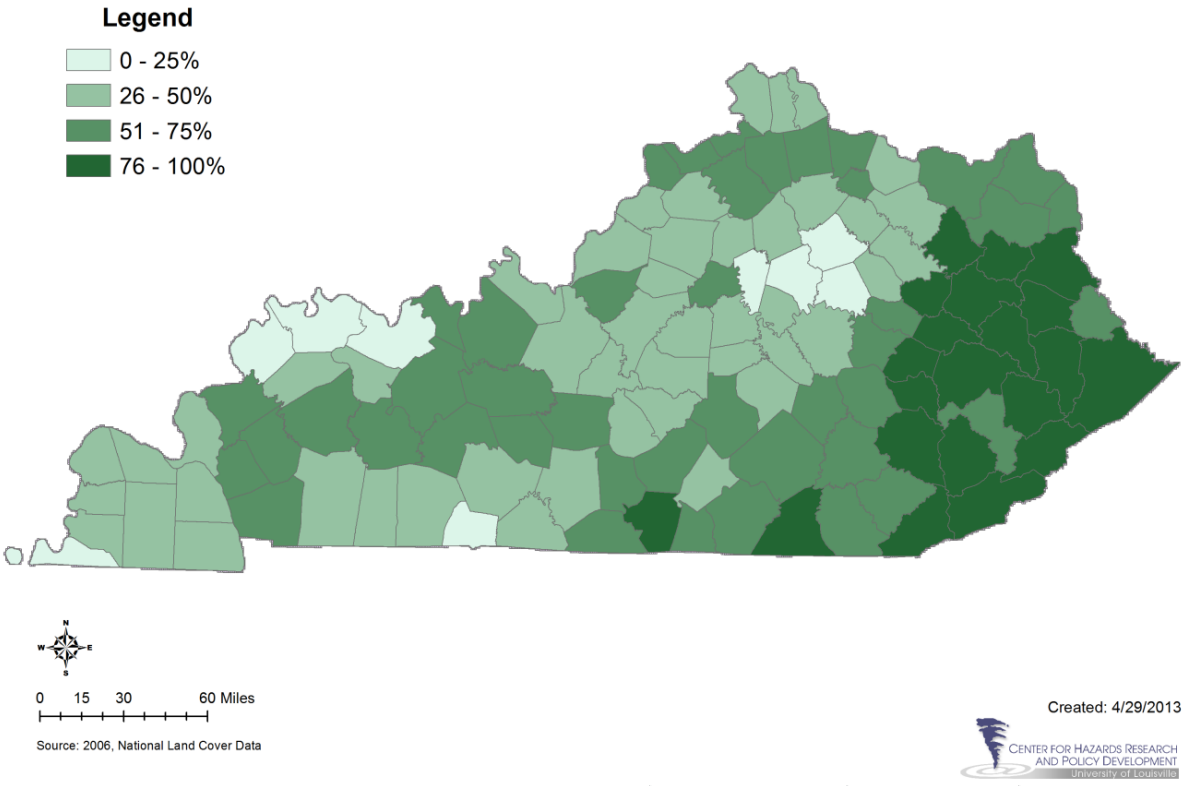
Kentucky's wildfire risks are compounded by the state's extremely high arson rate. Kentucky has the highest arson rate of all the 13 southern states. In fact, 62 percent of all wildfires in Kentucky are deliberately set by arsonists. Over 90 percent are human caused. These high numbers also represent a high potential for prevention efforts.

The area of Kentucky generally referred to as Appalachia poses the greatest wildfire risk within the state due to the mountainous terrain, limited access roads, and high arson occurrence. This area is the most heavily forested area of the state and heavier fuel loading increases the risks of wildfire [KDF 2013[8], *See* ***Appendix 4-2***]."

[7]Reeves, Christopher D. and Jeffrey W. Stringer. [2010]. "Economic Impact on Forest Product Values in the Appalachian Region of Kentucky and Tennessee." Lexington, KY: University of Kentucky College of Agriculture Cooperative Extension Service. *Cited within:* Division of Forestry (KDF). [2013]. "Hazard Identification: Wildfire." Unpublished Report. Frankfort, KY: Kentucky Energy and Environment Cabinet - Department for Natural Resources: Division of Forestry.

[8] Division of Forestry (KDF). [2013]. "Hazard Identification: Wildfire." Unpublished Report. Frankfort, KY: Kentucky Energy and Environment Cabinet – Department for Natural Resources: Division of Forestry. *[A copy of this report has been appended to this plan:* ***Appendix 4-2****].*

Percentage of Forest Land (areas over 3 acres) by County



Oak-hickory is the dominant forest cover and covers 8.4 million acres, or 72 percent of the state's forested land. Oak-pine forests make up 9 percent, maple-beech-birch and aspen-birch make up 7 percent, oak-gum-cypress and elm-ash-cottonwood make up 6 percent, softwood makes up 5 percent, and non-stocked, 1 percent.

Intentionally setting a fire on a land owned by another is illegal in Kentucky Revised Statute (KRS 149.380). The penalties include a fine of no less than $1,000 or more than $10,000, imprisonment for not more than five (5) years, or both fine and imprisonment.

The Kentucky Division of Forestry is responsible for fighting forest fires on private lands and enforcing forest first

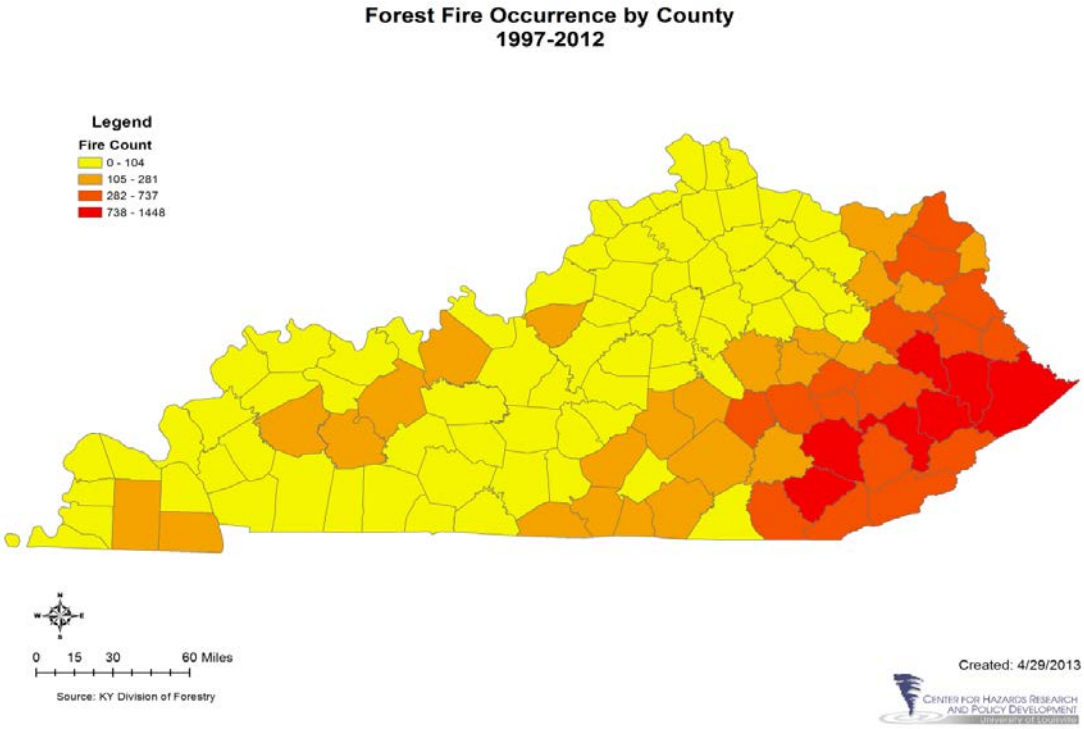
Kentucky Fire and Acres Burned 2003-2012		
Year	No. of Fires	Acres Burned
2003	927	19,699
2004	1,470	26,916
2005	1,710	51,587
2006	1,857	49,759
2007	1,956	52,506
2008	1,480	34,381
2009	1,369	40,934
2010	1,830	54,577
2011	1,002	23,090
2012	1,234	32,855
TOTALS	14,835	386,305

Source: KY Division of Forestry Wildland Fire Management. Retrieved on: April 29, 2013 at http://forestry.ky.gov/wildlandfiremanagement/Pages/default.aspx

hazard seasons and other outdoor burning regulations. Although the lead agency, there is no one agency that can fight all the forest fires in Kentucky.

"The Kentucky Division of Forestry protects nearly 12 million acres of privately owned forest acres across the state. The mission statement for the Division is to protect, conserve and enhance the forest resources of the Commonwealth through a public informed of the environmental, social, and economic importance of these resources. The Division currently has 146 full time employees, made up of foresters, county rangers, and tree nursery workers. In 2013 KDF restructured its nine district offices into five regional offices, concentrating resources and personnel to more efficiently meet the state's fire suppression and forest stewardship challenges [KDF 2013[9], *See* ***Appendix 4-2***]."

For data used to develop the forest fire profile, reports and statistics from Wildland Fire Management Branch provide updated information daily throughout the fire hazard season and periodically throughout the year.



[9] Division of Forestry (KDF). [2013]. "Hazard Identification: Wildfire." Unpublished Report. Frankfort, KY: Kentucky Energy and Environment Cabinet – Department for Natural Resources: Division of Forestry. *[A copy of this report has been appended to this plan:* ***Appendix 4-2****].*

Assessing Vulnerability by Jurisdiction: Forest Fire

Grid-Level Risk Assessment Model

Forest Fire Vulnerability Score = Exposure Score + Hazard Score

Assessing Kentucky's vulnerability to Forest Fire was determined through first calculating the Forest Fire Hazard Score. The Forest Fire Hazard Score was calculated by studying two (2) sources of data. The first layer used to create the Forest Fire Hazard Score was derived from the USGS NLCD land cover GIS map layer. This layer was used to calculate three (3) acre or higher forested areas to display forest fire potential. The NLCD land cover layer displays a geo-referenced data layer that depicts where forest fire potential could be based on three (3) acre forest coverage. To analyze Kentucky's risk to forest fire, the forest fire layer was overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based on the percent of the area the forest fire layer covered within each grid. This percentage of area affected by the forest fire potential areas was then calculated and scored 0-1 to develop 50% of the Forest Fire Hazard Score.

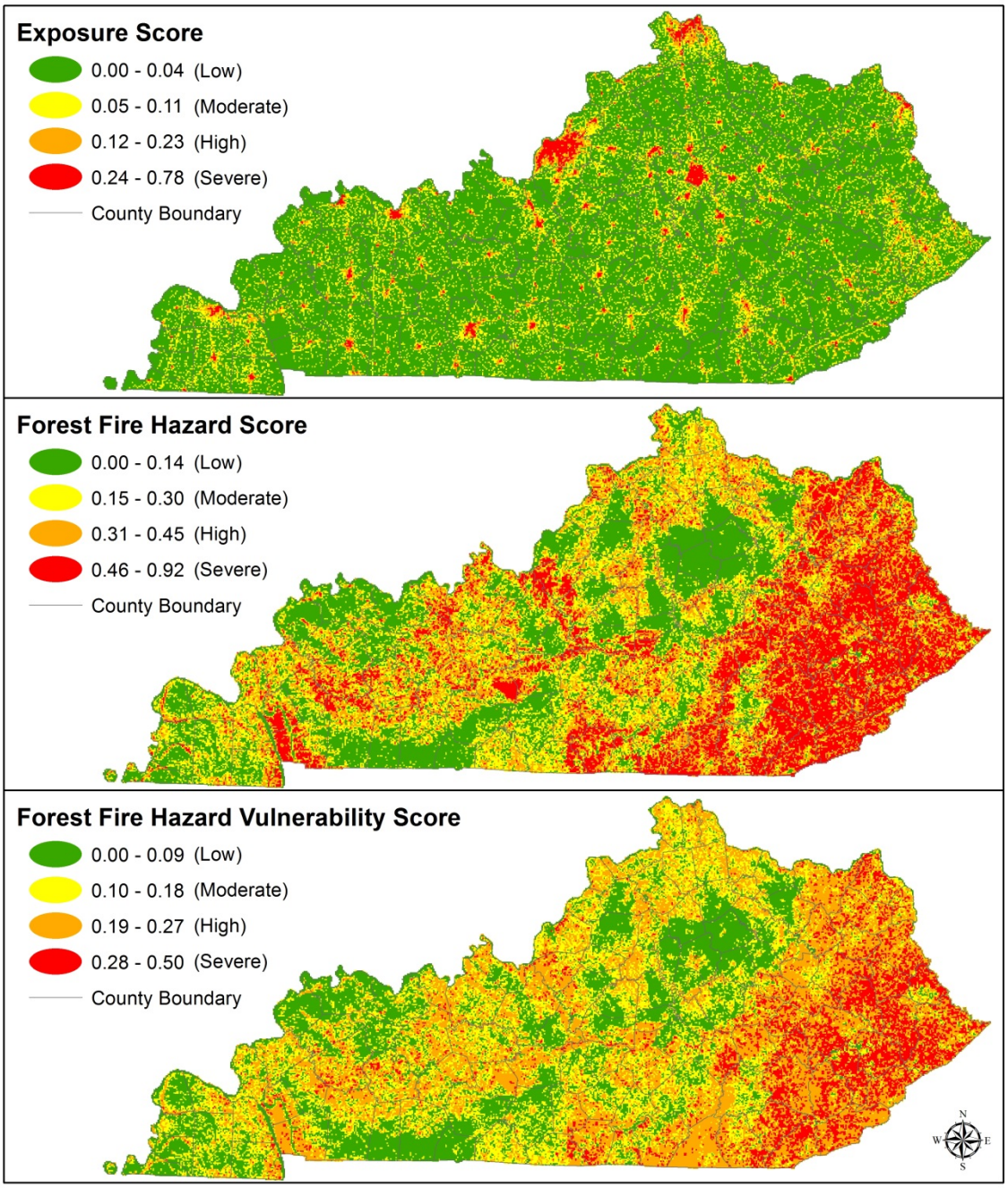
The next step was determined by calculating the number of forest fire points. This point data acquired from Kentucky Division of Forestry (KDF), displayed where concentrations of forest fires have occurred, thus producing areas of risk. The KDF forest fire point layer displays a geo-referenced data layer that depicts where forest fires have been identified. To analyze Kentucky's risk to forest fire, the KDF forest fire point layer was overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based the total number of forest fires that have occurred within each grid. The total number was then calculated for each grid and scored 0-1 to develop 50% of the Forest Fire Hazard Score.

The Forest Fire Hazard Score was then calculated by adding the two (2) scores together and scored 0-1. It is important to note if the Forest Fire Hazard Score inputs equaled 0, then the Forest Fire Hazard Vulnerability Score equaled 0.

Finally, the Forest Fire Vulnerability Score was calculated for each 1 KM MGRS grid by adding each grid's Exposure Score by its Forest Fire Hazard Score and then scored 0-1. Once the final Forest Fire Vulnerability Scores were calculated the composite scores were broken into four (4) categories, using the Natural Breaks classification system (1. Low, 2. Moderate, 3. High, 4. Severe) which demonstrates different levels of vulnerability displayed on the map.

The Grid-Level Risk Assessment Model should be used to identify specific areas of vulnerability located throughout Kentucky. This model provides 106,178 equal areas of comparison for the end users to assess hazard vulnerability. The best way to view and use this data is through a GIS viewer.

The following map displays the maps and components of the Forest Fire Vulnerability Score.



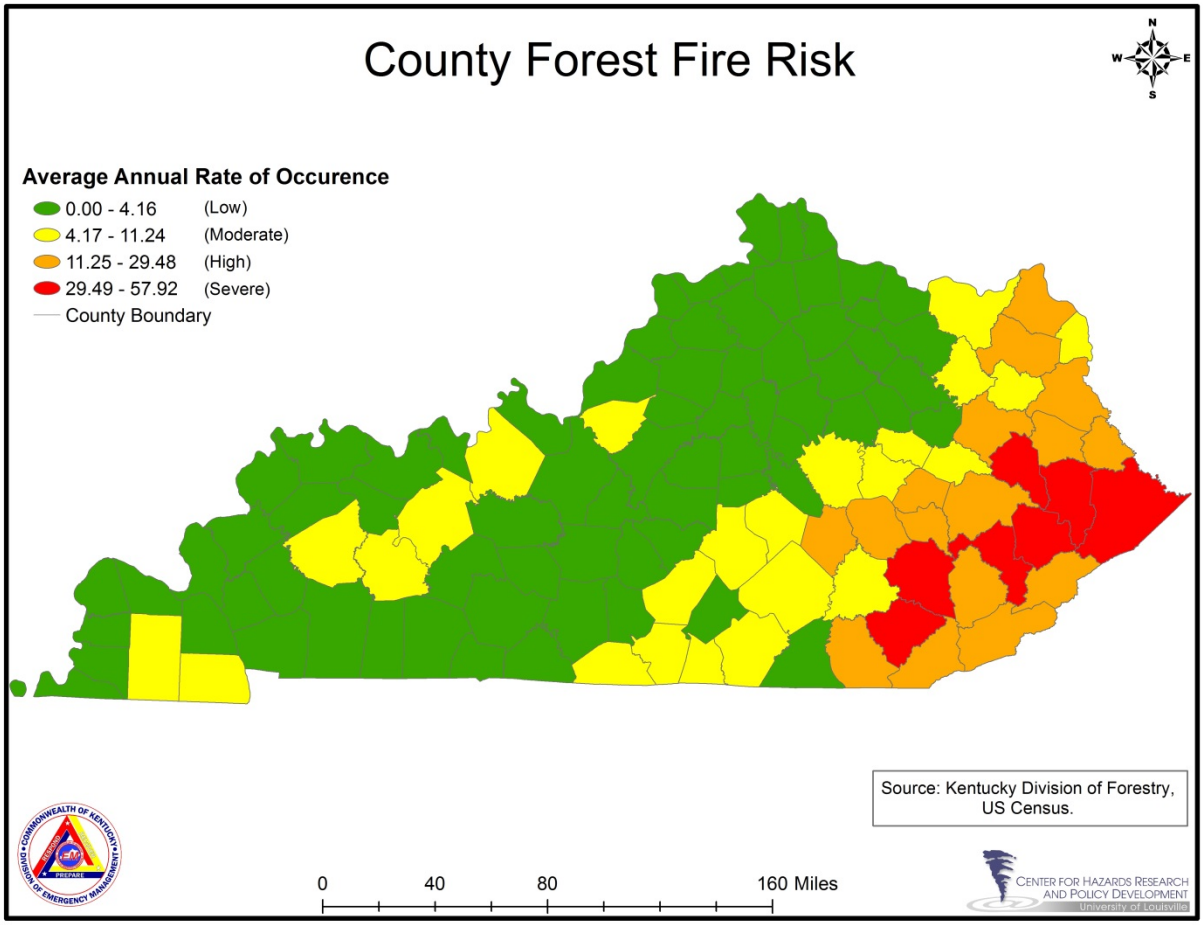
Source: Exposure- Division of State Risk and Insurance, ESRI, Kentucky Infrastructure Authority, Kentucky Office of Geographic Information, Kentucky Transportation Cabinet, KYEM, Public Service Commission, and the US Census Bureau. Hazard: Kentucky Division of Forestry, USGS

0 30 60 120 Miles

CENTER FOR HAZARDS RESEARCH AND POLICY DEVELOPMENT
University of Louisville

County-Level Risk Assessment Model

The Forest Fire County Risk Assessment Model was created using the Forrest Fire Average Annual Loss data for each county. The average annual loss is calculated by multiplying each county's annual rate of occurrence by their average losses (See ***Appendix 3-2*** "Hazard Average Annualized Loss"). This data was then joined to a county map for display as seen below.



The County-Level Risk Assessment Model should be used to compare county-level risk. This data depicts which counties are experiencing the most occurrences of forest fire comparatively across Kentucky.

Hazard Category: SEVERE WEATHER

Drought

Identifying Hazards: Drought

Description

Drought is a natural and recurring feature of Kentucky's climate that can be considered a "severe" weather event much like a tornado, a flood, or a hurricane. However, there are few key differences which distinguish drought from other weather events, making it difficult to detect and track.

Part of the difficulty in detecting drought is in the lack of an obvious onset of drought conditions. A drought develops slowly and can appear to mimic a normal spell of dry weather in the summer, a time of the year when dry weather is accepted and expected. Short-term rainfall shortages create problems for agricultural crops, livestock, urban landscapes, and other activities that depend on stored soil moisture between rainfall events.

Despite all of the problems that droughts cause, drought has proven to be difficult to define. There is no universally accepted definition because drought, unlike flooding for example, is not a distinct event. Additionally, drought is often the result of many complex factors and has no well-defined start or end. The impacts of drought may again vary by affected sector, thus making definitions of drought specific to particular situations.

The most commonly used drought definitions are based on meteorological, agricultural, hydrological, and socioeconomic effects.

Meteorological drought is defined as a period of substantially diminished precipitation duration or intensity. The commonly used definition of meteorological drought is an interval of time, generally on the order of months or years, during which the actual moisture supply at a given place consistently falls below the climatically appropriate moisture supply.

Agricultural drought occurs when there is inadequate soil moisture to meet the needs of a particular crop at a particular time. Agricultural drought usually occurs after or during meteorological drought but before hydrological drought. It can also affect livestock and other dry-land agricultural operations.

Hydrological drought refers to deficiencies in surface and subsurface water supplies. There is usually a delay between lack of rain or snow and less measurable water in streams, lakes, and reservoirs. Therefore, hydrological measurements tend to lag other drought indicators.

Socioeconomic drought occurs when physical water shortages start to affect the health, well-being, and quality of life of the people, or when the drought begins to affect the supply and demand of an economic product.

Types

There are many different indices for measuring drought. Although none are superior to the others, some indices are better for certain situations. The Palmer Drought Severity Index (PDSI) is currently used by the U.S. Department of Agriculture to help determine when grant assistance is needed. This index is also helpful for areas of widely similar topography. As Kentucky has relatively similar topography (with exceptions in the eastern portion of the state) and also has a great deal of agriculture, the PDSI will be used in the state plan. The index measures the level of recorded precipitation against the average, or normal, amount of precipitation for a region.

Palmer Classifications System (PDSI)	
+4.0 in. or more	extremely wet
3.0 in to 3.99 in	very wet
2.0 in to 2.99 in	moderately wet
1.0 in to 1.99 in	slightly wet
0.5 in to 0.99 in	incipient wet spell
0.49 in to -0.49 in	near normal
-0.5 in to -0.99 in	incipient dry spell
-1.9 in to -1.99 in	mild drought
-2.0 in to -2.99 in	moderate drought
-3.0 in to -3.99 in	severe drought
-4.0 in or less	extreme drought

Source: National Oceanic and Atmospheric Association (NOAA)

Facts

- High temperatures, prolonged high winds, and low relative humidity can aggravate drought conditions.
- Droughts can lead to economic losses such as unemployment, decreased land values, and agribusiness losses.
- In 2011, in Texas alone, almost 2.5 billion dollars in property and crop damages were attributed to drought.

Primary Impacts

- Crop failure is the most crucial effect of drought. Drought has a direct impact on the economy and in many cases the health of the population that is affected. Due to a lack of water and moisture in the soil, many crops will not produce normally or efficiently and in many cases, may be lost entirely.
- Water shortage is a very serious effect of drought. The availability of potable water is severely decreased when drought conditions persist. Springs, wells, streams, and reservoirs have been known to run dry due to the decrease in ground water, and, in extreme cases, rivers have become unsafe for navigation as a result of drought.

Secondary Impacts

- Fire susceptibility is increased with the absence of moisture associated with a drought. Dry conditions have been known to promote the occurrence of widespread wildfires.

Tertiary Impacts

- Environmental degradation via erosion and ecological damage can be additional results of drought. As moisture in topsoil dissipates and the ground becomes dryer, the susceptibility to windblown erosion increases. In prolonged drought situations loss of habitat for certain species native to that particular environment is possible. Prolonged drought conditions may also result in loss of food sources for certain species.
- In prolonged drought situations the soil surrounding structures subsides, sometimes creating cracks in foundations and separation of foundations from above ground portions of the structure. Forest root systems may be damaged or destroyed through a similar process.

Profiling Hazards: Drought

FOREST FIRE PROFILE RISK TABLE	
Period of occurrence:	Drought can occur at any time of the year in any part of Kentucky
Number of events: (1960-2013)	121*
Annual Rate of Occurrence:	2.28
Warning time:	Warning times for drought are not applicable as they are for severe storms or winter weather. Drought is onset by a period of similar weather and precipitation conditions. Predictability and preparedness is based mostly on the awareness of populations drought conditions are affecting.
Potential impacts:	Impacts to human life, health, and public safety are possible. Utility damage and failure, infrastructure damage (transportation and communication systems), structural damage, potential increase in risk of wild fire, and the possibility of damaged or destroyed critical facilities are additional impacts. Most impacts result from wildfire, extreme dry conditions, or dust storms.
Recorded losses:	$301,317,375*
Annualized Loss:	$2,490,226
Extent (Historical & Scale):	Year: 1996 Scale: 1.5 inches of rain measured between July and September Damages: $155 M in crop losses

*Data captured from SHELDUS 10.1 (occurrence data captures county-level events across the state)

Kentucky Drought Action Levels

Drought Advisories

Drought Level I: "Official" recognition of drought

Drought Level II: Serious impacts to human and environment

Drought Level III: Substantial impacts to human and environment

A Level 1 drought indicates moderate drought conditions have developed primarily affecting soil moisture and vegetative health. Serious impacts to agricultural water needs, an increased wildfire risk, water supply shortages with systems on small lakes and reservoirs, and other water-sensitive sectors can be expected in the designated areas.

A Drought Level I declaration will be considered when at least three (3) of the five (5) indicators meet the trigger threshold. At this stage of drought it is expected that some level of drought impact will be observed in one or more drought management regions.

A Level 2 drought indicates that the Level 1 risks are becoming an actuality. Low stream flows and lower-than-normal lake levels could lead to water conservation advisories and/or mandatory restrictions on water use.

A Drought Level II declaration will be considered when at least three (3) of the five (5) indicators meet the trigger threshold. At this stage of drought it is expected that drought impacts, some severe, will be observed in all of the affected drought management regions including:

- Moderate to severe impacts to water-sensitive enterprises
- Unusually high demands placed on water treatment facilities
- Depletion of water supplies in shallow wells, springs and small ponds
- Reports of water conservation advisories from communities with drought-vulnerable sources of supply
- Increased incidence wildland and residential fires

A Drought Level III declaration will be considered when at least three (3) of the five (5) indicators meet the trigger threshold. During this stage of drought it is expected that drought impacts will be widespread and severe and develop into emergencies if drought conditions are not abated, including:

- Severe to extreme impacts to water-sensitive enterprises
- Loss of water supplies in shallow wells, springs and small ponds
- Multiple occurrences of water utilities requiring mandatory water-use restrictions or declaring local water shortage emergencies

- Critical low streamflows impacting water quality and aquatic habitat
- Frequent reports of water utilities having difficulties with adequate treatment for iron or manganese, or with taste and odor problems
- Critically low flows in some major rivers that provide drinking water to large population centers in the drought management regions
- Increased incidence of conflicts between users of diminishing water resources
- Increased incidence wildland and residential fires

Although bits and pieces of data on drought occurrence exist, most of the information is in the form of news reports and historical records. As referenced in Drought's description above, the Palmer Drought Severity Index (PDSI) is the most widely used measurement of drought severity. Unfortunately, significant figures and information regarding these periods of drought are difficult to find, if they even exist at all.

For example, NOAA NCDC data indicated 32 state-wide drought events, where SHELDUS showed only two (2) state-wide significant events since 1999. 2007 was recorded as being one of the driest years since the 1940's and 2012 was the worst drought year since the 1950s for the entire country as well as Kentucky yet no in depth data has been found on the effects of this particular drought.

According to NOAA, there have been 16 recorded drought occurrences in Kentucky since 1996. Only three (3) of those droughts caused serious damage to agricultural yields. The 1996 drought affected 20 counties in western Kentucky with crop damages assessed around $154 million. In 2002, 22 counties in Kentucky were affected with losses assessed at $70 million. Drought in 2007 again affected 22 counties in western Kentucky, resulting in a loss of over $48 million in crop damages. There were no injuries or deaths reported as a result of these droughts.

During periods of drought in Kentucky, some activities which rely heavily on high water usage may be impacted significantly. These activities include agriculture, tourism, wildlife protection, municipal water usage, recreation, wildlife preservation, and electric power generation.

The severe summer drought of 1996 took a major toll on crops and plants across the state. Rainfall at Paducah, Kentucky was only one and a half inches from July through September of that year. Paducah usually receives around ten inches of rain for that period. Soybean crops sustained the greatest losses, estimated near $70 million. Additionally, tobacco losses amounted to $50 million and corn losses approached $35 million. Total crop losses in western Kentucky alone were near $155 million, which prompted an agricultural disaster declaration by state and federal governments. The root systems of many shrubs and young trees were damaged. Many died as a result of the drought.

Other, large-scale effects of the 1996 drought can be seen in fire damage and water shortages. During the drought, the danger of wild fire reached extreme levels. The largest fire occurred east of Central City in Muhlenberg County. It eventually covered close to 1,000 acres, prompting the closure of the Western Kentucky Parkway for several hours. Another large fire, estimated as having a burn area of around 500 acres, ignited in Hickman County. This fire, which may have been sparked by a passing train, burned numerous corn and soybean fields. Finally, a 100-acre cornfield fire near Henderson Kentucky closed the Pennyrile Parkway for about an hour and forced the brief evacuation of a local nursing home. The Kentucky Division of Water declared a water shortage warning for the Pennyrile area, which includes the cities of Owensboro and Hopkinsville. No mandatory water conservation measures were imposed however.

In August of 2007 drought had firmly established itself in the southeastern U.S. by late spring 2007, and began swelling northward during the early summer. By mid-June southern Kentucky had entered a severe drought with precipitation deficits since January 1 on the order of eight inches.

The severe drought conditions continued to spread northward, and all of central Kentucky felt the effects by the end of June. The Commonwealth issued a Water Shortage Watch for 61 central Kentucky counties. Burn bans went into effect and the Green River Ferry in mammoth Cave National Park discontinued service because of low water levels. A few counties imposed water restrictions on residents. The Tennessee Valley Authority placed a fuel surcharge of $3 to $6 per month per customer on electricity.

During this event, searing heat baked Kentucky, creating significant stress on agricultural concerns and water supplies. Temperatures soaring into the 90s nearly every day and over 100 degrees on several occasions, combined with continued low overall rainfall amounts, locked the region firmly in drought. By the third week of the month roughly the southern half of Kentucky had descended into extreme drought, with severe drought conditions crossing the Ohio River into southern Indiana. People from Logan County to Nelson County to Casey County were about sixteen inches below normal for rainfall since the beginning of the year.

The number of wildfires in Kentucky increased 500% over the previous summer. In southern Kentucky soil moisture was about half of what it should have been, and 17 counties became eligible for Federal aid. The Barren River at Bowling Green was at its lowest point since the Barren River Dam was erected in 1963.

In October of 2010, a drought declaration was issued for 50 counties in seven DMAs under a Level 2 declaration and 35 counties in eight DMAs under a Level 1 declaration with agricultural disasters and wildfires becoming a major concern. As of October 12, 38 Kentucky counties were under burn bans.

Assessing Vulnerability by Jurisdiction: Drought

Grid-Level Risk Assessment Model

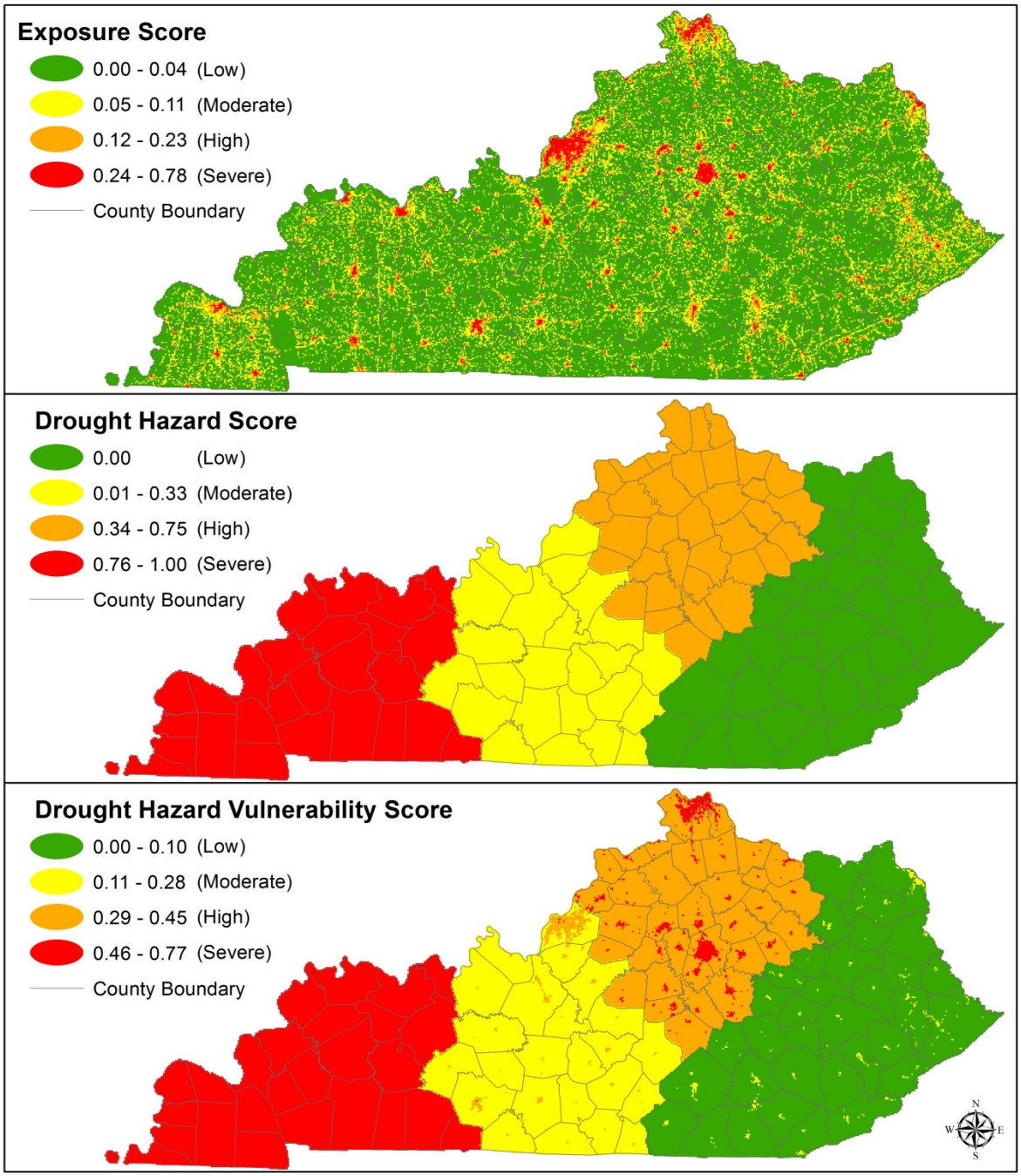
Drought Vulnerability Score = Exposure Score + Hazard Score

Assessing Kentucky's vulnerability to Drought was determined through first calculating the Drought Hazard Score. The Drought Hazard Score was calculated by studying one (1) specific source of data. The data layer used to create the Drought Hazard Score was data collected from the Palmer Drought Severity Index (PDSI) from 1895-2013. In order to use this data for the Drought Hazard Score an average PDSI was calculated for each of the four (4) PDSI regions in Kentucky using the annual PDSI from 1895-2013. This created four (4) specific hazard areas to score from. To analyze Kentucky's risk to Drought, the PDSI layer was overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based on the percent of the area the PDSI layer covered within each grid. This percentage of area affected by the mapped PDSI areas (4) was then calculated and scored 0-1 to develop the Drought Hazard Score.

The Drought Vulnerability Score was calculated for each 1 KM MGRS grid by adding each grid's Exposure Score by its Drought Hazard Score and then scored 0-1. Once the final Drought Vulnerability Scores were calculated the composite scores were broken into four (4) categories, using the Natural Breaks classification system (1. Low, 2. Moderate, 3. High, 4. Severe) which demonstrates different levels of vulnerability displayed on the map.

The Grid-Level Risk Assessment Model should be used to identify specific areas of vulnerability located throughout Kentucky. This model provides 106,178 equal areas of comparison for the end users to assess hazard vulnerability. The best way to view and use this data is through a GIS viewer.

The following map displays the maps and components of the Drought Vulnerability Score.



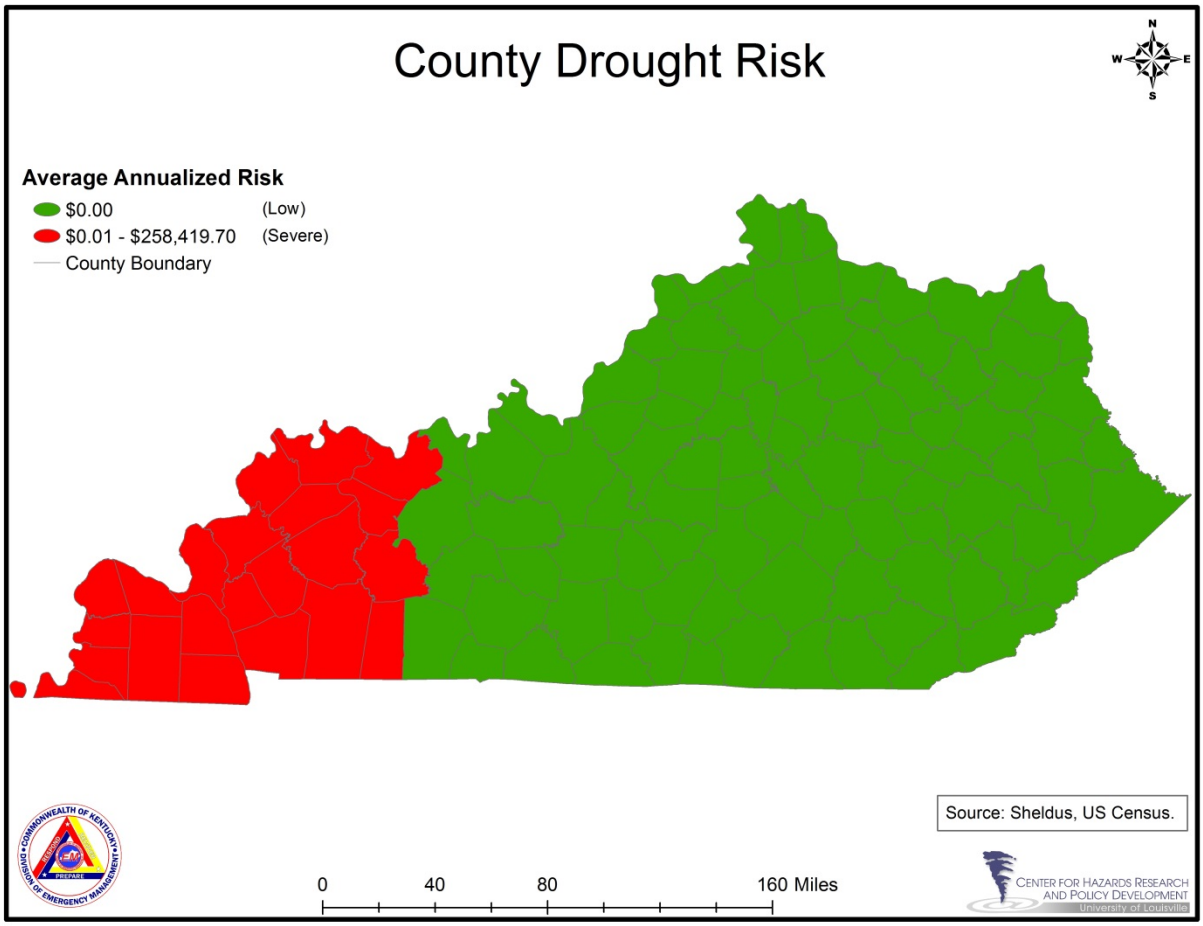
Source: Exposure- Division of State Risk and Insurance, ESRI, Kentucky Infrastructure Authority, Kentucky Office of Geographic Information, Kentucky Transportation Cabinet, KYEM, Public Service Commission, and the US Census Bureau. Hazard: NOAA

0 30 60 120 Miles

CENTER FOR HAZARDS RESEARCH AND POLICY DEVELOPMENT
University of Louisville

County-Level Risk Assessment Model

The Drought County Risk Assessment Model was created using the Drought Average Annual Loss data for each county. The average annual loss is calculated by multiplying each county's annual rate of occurrence by their average losses (See ***Appendix 3-2*** "Hazard Average Annualized Loss"). This data was then joined to a county map for display as seen below.



The County-Level Risk Assessment Model should be used to compare county-level risk. This data depicts which counties are experiencing the most occurrences and losses from drought comparatively across Kentucky.

Extreme Temperature

Identifying Hazards: Extreme Temperature

Description

Extreme Heat

Conditions of extreme heat are defined as temperatures that are substantially hotter and/or more humid than average for a location during a particular (usually summer) time of year. Humid or muggy conditions, which add to the discomfort of high temperatures, occur when a "dome" of high atmospheric pressure traps hazy, damp air near the ground.

Wildfires and droughts are aggravated and sometimes caused by periods of extreme heat. As drought and wildfires have their own profiles, heat-related illness is the main focus of this hazard identification.

Heat-related illness most often occurs when the body's temperature control system is overloaded. The body normally cools itself by sweating, but sometimes lacks the capacity to keep the body cooled to a safe temperature. When the natural cooling process fails, a person's body temperature rises rapidly. Very high body temperatures may damage the brain or other vital organs. Several factors affect the body's ability to cool itself during extremely hot weather. When humidity is high, sweat will not evaporate as quickly, preventing the body from releasing heat quickly. This is a major concern in Kentucky as significant humidity levels are common year round.

Impacts
(Listed in order of greatest to least severity)

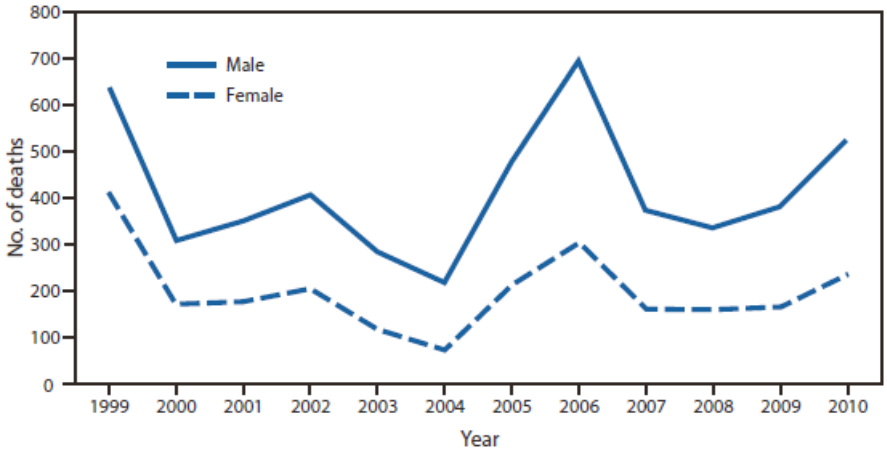
- *Heat Stroke:* Heat stroke occurs when the body is unable to regulate its temperature. The body's temperature rises rapidly, the sweating mechanism fails, and the body is unable to cool down. Body temperature may rise to 106°F or higher within 10 to 15 minutes. Heat stroke can cause death or permanent disability if emergency treatment is not provided.
- *Heat Exhaustion:* Heat exhaustion is a milder form of heat-related illness that can develop after several days of exposure to high temperatures and inadequate or unbalanced replacement of fluids. It is the body's response to an excessive loss of the water and salt contained in sweat. Those most prone to heat exhaustion are elderly people, people with high blood pressure, and people working or exercising in a hot environment.
- *Heat Cramps:* Heat cramps usually affect people who sweat a lot during strenuous activity. This sweating depletes the body's salt and moisture. The low salt level in the muscles may be the cause of heat cramps. Heat cramps may also be a symptom of heat exhaustion.

- *Sunburn:* Sunburn should be avoided because it damages the skin. Although the discomfort is usually minor and healing often occurs in about a week, more severe sunburns may require medical attention.
- *Heat Rash:* Heat rash is a skin irritation caused by excessive sweating during hot, humid weather. It can occur at any age but is most common in young children.

Facts

- Heat is the number one weather-related killer in the United States and claims more lives each than floods, lightning, tornadoes, and hurricanes combined.
- In a normal year, hundreds of Americans die from extreme heat. Young children, elderly people, and those who are sick or overweight are more likely to become victims.
- Sunburn can significantly slow the skin's ability to release excess heat.
- Because men sweat more than women, men are more susceptible to heat illness because they become dehydrated more quickly.
- Between 1936 and 1975, nearly 20,000 people died as a result of heat and solar radiation.
- In the disastrous heat wave of 1980, more than 1,250 people died nationwide.
- In the heat wave of 1995, more than 700 people died in the Chicago area.
- The record heat wave in August 2003 claimed an estimated 50,000 lives in Europe.
- From 1999 to 2010, a total of 7,415 deaths in the United States, an average of 618 per year, were associated with exposure to excessive heat.

Number of Heat-Related Deaths, United States, 1999-2010



(Source: CDC, http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6136a6.htm)

The following graphic depicts the National Weather Services' "Heat Index". The Heat Index is the temperature the body feels when heat and humidity are combined. Although extreme heat can be either extremely humid or extremely dry, there are several types of heat-related illness that result due to exposure to this hazard. Potential impacts are also assumed to only involve the human factor (an individual's health) as additional information on drought and wildfires are found in their respective identification sections.

NOAA's National Weather Service

Heat Index

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution | Extreme Caution | Danger | Extreme Danger

(Source: http://www.nws.noaa.gov/om/heat/index.shtml)

Extreme Cold

What constitutes extreme cold and its effect varies across different areas of the United States. In areas unaccustomed to winter weather, near freezing temperatures are considered "extreme cold." In the north, below zero temperatures may be considered as "extreme cold." Extreme cold often accompanies a winter storm or is left in its wake.

Whenever temperatures drop decidedly below normal and as wind speed increases, heat can leave your body more rapidly. These weather related conditions may lead to serious health problems. Extreme cold is a dangerous situation that can bring on health emergencies in susceptible people, such as those without shelter or who are stranded, or who live in a home that is poorly insulated or without heat. Prolonged exposure to the cold can cause frostbite or hypothermia and become life-threatening. Infants and elderly people are most susceptible.

Freezing temperatures can also cause severe damage to citrus fruit crops and other vegetation. Pipes may freeze and burst in homes that are poorly insulated or without heat. Long cold spells can cause rivers to freeze, disrupting shipping. Ice jams may form and lead to flooding.

Impacts

- *Frostbite:* Frostbite is an injury to the body that is caused by freezing. Frostbite causes a loss of feeling and color in affected areas. It most often affects the nose, ears, cheeks, chin, fingers, or toes. Frostbite can permanently damage the body, and severe cases can lead to amputation. The risk of frostbite is increased in people with reduced blood circulation and among people who are not dressed properly for extremely cold temperatures.
- *Hypothermia:* When exposed to cold temperatures, your body begins to lose heat faster than it can be produced. Prolonged exposure to cold will eventually use up your body's stored energy. The result is hypothermia, or abnormally low body temperature. Body temperature that is too low affects the brain, making the victim unable to think clearly or move well. This makes hypothermia particularly dangerous because a person may not know it is happening and won't be able to do anything about it. Hypothermia is most likely at very cold temperatures, but it can occur even at cool temperatures (above 40°F) if a person becomes chilled from rain, sweat, or submersion in cold water.

Facts

- The National Weather Service refers to winter storms as the "Deceptive Killers" because most deaths are indirectly related to the storm. Instead, people die in traffic accidents on icy roads and of hypothermia from prolonged exposure to cold.
- Infants lose body heat more easily than adults and unlike adults, infants can't make enough body heat by shivering.
- Older adults often make less body heat because of a slower metabolism and less physical activity.
- During 1979-2002, a total of 16,555 deaths in the United States, an average of 689 per year, were attributed to exposure to excessive natural cold (hypothermia).

During the winter, a breeze can make a cold day feel more uncomfortable. That's because wind drives heat away from exposed skin faster than calm air. High winds combined with very low temperatures create dangerously cold conditions. To help people understand the risk, NOAA's National Weather Service provides wind chill temperatures in reports of current conditions and in forecasts. While dangerous wind chills occur regularly in the northern plains, they can also affect almost any region in the United States. As temperatures drop below freezing, exposed skin is at risk of frostbite and you become more susceptible to hypothermia. The lower the wind chill temperature, the faster frostbite or hypothermia can occur.

NOAA's National Weather Service wind chill chart shows the increasing dangers as temperature drops and wind speed increases. In cold winter months, National Weather

Service weather forecast offices routinely issue two types of alerts to warn people about dangerously low wind chill temperatures.

- A *Wind Chill Advisory* is issued when wind chill temperatures are potentially hazardous.
- A *Wind Chill Warning* is issued when wind chill temperatures are life threatening.

However, temperature criteria for an advisory or warning can vary from state to state to reflect regional climate differences.

NWS Windchill Chart

Wind (mph) \ Temperature (°F)	Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5		36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10		34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15		32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20		30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25		29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30		28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35		28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40		27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45		26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50		26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55		25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60		25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times: 30 minutes, 10 minutes, 5 minutes

$$\text{Wind Chill (°F)} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where, T= Air Temperature (°F) V= Wind Speed (mph)

Effective 11/01/01

(Source: NOAA/NWS, http://www.nws.noaa.gov/om/windchill/)

Profiling Hazards: Extreme Temperature

EXTREME TEMPERATURE PROFILE RISK TABLE	
Period of occurrence:	Extreme heat is most likely to occur in the months of July, August, or September. Extreme heat has been known to occur in May, June, and October. The likelihood of extreme heat occurring outside of these months is extremely small and unheard of December through March. Extreme cold is most likely to occur in the months of December, January or February.
Number of events: (1960-2013)	1,175*
Annual Rate of Occurrence:	22.17
Warning time:	The National Weather Service will initiate alert procedures when the Heat Index is expected to exceed 105°- 110°F (depending on local climate) for at least two consecutive days. Currently, there are no officially warnings for extreme cold. This was tested in 2012 but later dropped.
Potential impacts:	Extreme heat, impacts human life, health, and public safety. Fires due to extremely dry conditions are possible. Can lead to economic losses such as decreased land values and agribusiness losses. Extreme cold, impacts human life, health, and public safety. Rivers and lakes freeze causing transportation issues. Energy consumption goes up and depending on the time of year extreme cold can have large impacts on agriculture. Cold temperatures can also cause ruptured pipes and stressed on engines and motors.
Recorded losses:	$1,141,306*
Annualized Loss:	$21,534
Extent (Historical):	Date: 2012 Temperature: 94 degrees Impact: 1 death

*Data captured from SHELDUS 10.1 and NCDC. The number of events and recorded losses is a combination of both heat and cold events.

Background: Temperatures that hover 10 degrees or more above the average high temperature for the region are defined by NOAA as extreme heat. A temperature of 90°F is significant in that it ranks at the "caution" level of the NOAA's Apparent Temperature chart even if humidity is not a factor.

The 1952 heat wave lacked the intensity of other heat waves but it did have duration. According to the Kentucky Division of Forestry, numerous acres burned in 1952 due to the lack of precipitation.

1990 and 1991 saw consecutive heat waves in which 1991 caused a statewide drought. 1991 is the third warmest year on record and also contained the third warmest summer as well as the second warmest spring.

During the last two weeks of July 1999, the Midwest experienced a lengthy series of days with temperatures higher than 90 degrees F. While only a relatively small number of maximum temperature records were set, the combination of high heat, record dew points, strong solar inputs, and weak winds led to a dangerous situation for people. Before it was over, some 232 deaths were attributed to the heat in the 9-state area served by the MRCC; there were additional health, infrastructure, and economic impacts that were quite significant.

The major loss of life was in large cities where the urban heat island amplified temperatures by 3 to 5 degrees or more. The majority of those who died were elderly persons, living alone in the inner city regions, that either were without air conditioning or without the funds to pay for continuous operation of their air conditioning units. Most of the people, who died on the 29th and 30th, lived in large cities with aging and old infrastructure consisting of non-air-conditioned brick buildings.

In August 2007, nearly 30 temperature records were set in central Kentucky. The average temperature for August in Kentucky is around 77 degrees, give or take a few degrees per location. In 2007, the average was 85 degrees. August 2007 became the hottest month ever recorded at Louisville and Bowling Green, and the 3rd hottest on record at Lexington. A federal disaster designation by the U.S. Department of Agriculture was declared allowing farmers in the state's $4 billion-a-year industry to seek emergency assistance, including low-interest loans to help pay for essential farm and living expenses.

The summer of 2010 was one of the hottest on record across Kentucky. This is true with respect to both average temperature and minimum daily temperature. The summer was the 2nd warmest on record with maximum daily temperature (1952 had higher maximum temps).

According to NOAA, 2012 was the hottest year on record for the continental United States. Every year from 2010 to 2012 was in the top four (4) warmest summers recorded in Kentucky. 2010 had the most days over ninety degrees (85 days) and 2012 had 10 days over one hundred degrees.

Although these events cover a broad time span, it is still important to note what accompanies extreme heat. Kentucky is always at risk for extreme heat during peak occurrence months. Extreme heat not only causes droughts and crop damage, but also the loss of human life. Several accounts of heat-related deaths populate headlines

throughout warmer months for Kentucky. There was a case in Louisville, August 20, 2008, where a young man died due to heat-related complications resulting from football practice in 94 degree weather. As stated in the description section of the state plan, elderly people, young people, and persons who are of unhealthy weights are all at constant risk from the dangers of extreme heat.

Extreme Cold

As many incidents of extremely cold temperatures in Kentucky have accompanied other severe winter weather events and those events are discussed in their respective sections throughout this document, this section will focus only on the temperature element, of which there is little information available to report.

Along with the record snowfall in January 1994, Kentucky also set low temperature records across the state. The heavy snow set the stage for incredibly low temperatures, as behind the storm an intensely cold air mass dumped south out of Canada, sending temperatures plunging well below zero by Wednesday, January 19th. Not only did Louisville record an all-time low of -22 degrees, but Shelbyville set a new record low temperature for the entire state of Kentucky with a reading of -37 degrees. Lexington came within one degree of its all-time record low.

The great ice storm of 1951 also was accompanied by extremely low temperatures. From January 29-February 2, an extremely strong high-pressure system started making its way into the region, pulling harsh, cold, polar air in with it. In the meantime, a strong low pressure system was moving through areas farther south along a cold front, stretching from the Gulf of Mexico and up into the Northeast. This was the perfect set up for the development and occurrence of freezing rain and sleet along with freezing temperatures. Bowling Green recorded a temperature of -20 degrees, the coldest official temperature ever recorded in February up to that time. Water pipes burst under the extreme cold, transportation remained halted, temperatures remained unbearable, and ten days later the area had yet to recover from the ice and the snow.

In 2007, an example of an out of the ordinary extremely cold weather event and the potential devastation it can cause occurred throughout Kentucky. After an unusually warm streak the lasted ten days of March, with temperatures topping out in the 70s and 80s each day, a cold front made its way into the Ohio Valley Region on April 3. With the cold front came extensive severe weather, and afterwards replaced the once high temperatures with an immense area of cold Canadian air. Temperatures dipped into the 20s and 30s in the mornings between the 5th and the 10th throughout Kentucky. Bowling Green spent a total of 47 non-consecutive hours below freezing, with their lowest temperatures of 22 degrees Fahrenheit on the 8th of the month. Louisville and Lexington both recorded impressive lows as well, with Louisville reporting 25 degrees on the 7th and Lexington 22 degrees for both the 7th and 8th. Before the cold streak, the spring crops and plant growth were getting an early start with the excessive warmth for the time of season. However, as the cold air set in for the week, the below freezing temperatures took advantage of the blooming vegetation. Nearly all crops suffered losses, including most of the state's peaches. Half the wheat crop was destroyed, estimated at 63 million dollars' worth of losses. The same was true for the area's corn crop, which reported 5 million dollars in losses. 16 million was reported in damages for a 20 million dollar fruit industry, nearly crippling it.

The massive ice storm of 2009 that swept destruction throughout the state was also coupled with extremely cold weather. Most areas of the state saw temperatures fall to below freezing and wind chills below zero. This exacerbated the challenge of recovering from the storm by allowing the ice to linger even longer and making it even more difficult for work crews to clean up the debris and restore power to peoples' homes.

Assessing Vulnerability by Jurisdiction: Extreme Temperature

Grid-Level Risk Assessment Model

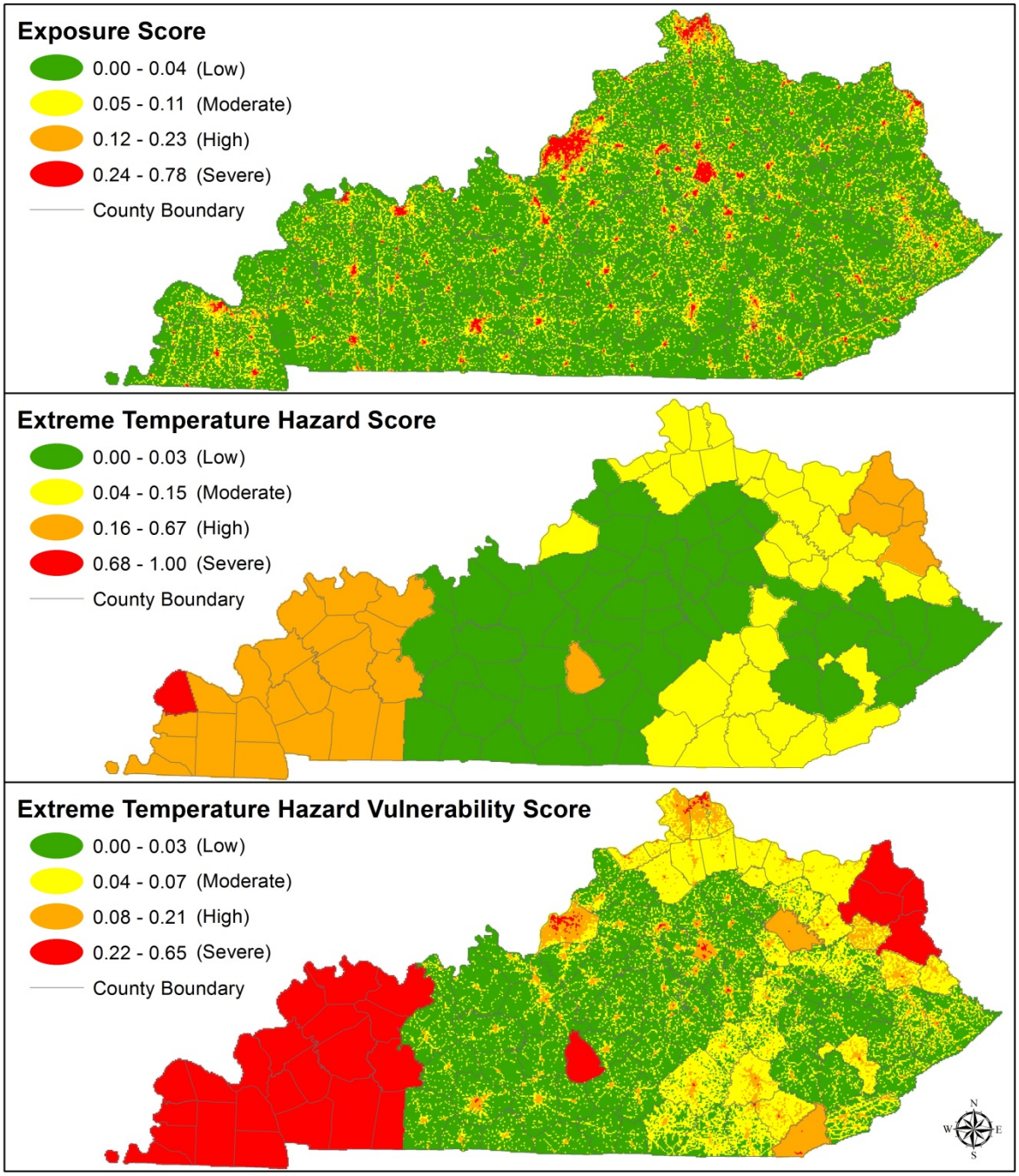
Extreme Temperature Vulnerability Score = Exposure Score + Hazard Score

Assessing Kentucky's vulnerability to Extreme Temperature was determined through first calculating the Extreme Temperature Hazard Score. The Extreme Temperature Hazard Score was calculated by studying one (1) specific source of data. The data layer used to create the Extreme Temperature Hazard Score was data collected from the capturing county-level extreme temperature events. In order to use this data for the Extreme Temperature Hazard Score each county was assigned their maximum number of events and that data was aggregated to each grid within that county. To analyze Kentucky's risk to extreme temperature, the county extreme temperature layer was overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based on the percent of the area the extreme temperature layer covered within each grid. This percentage of area affected by the extreme temperature layer was then calculated and scored 0-1 to develop the Extreme Temperature Hazard Score.

The Extreme Temperature Vulnerability Score was calculated for each 1 KM MGRS grid by adding each grid's Exposure Score by its Extreme Temperature Hazard Score and then scored 0-1. Once the final Extreme Temperature Vulnerability Scores were calculated the composite scores were broken into four (4) categories, using the Natural Breaks classification system (1. Low, 2. Moderate, 3. High, 4. Severe), which demonstrates different levels of vulnerability displayed on the map.

The Grid-Level Risk Assessment Model should be used to identify specific areas of vulnerability located throughout Kentucky. This model provides 106,178 equal areas of comparison for the end users to assess hazard vulnerability. The best way to view and use this data is through a GIS viewer.

The following map displays the maps and components of the Extreme Temperature Vulnerability Score.



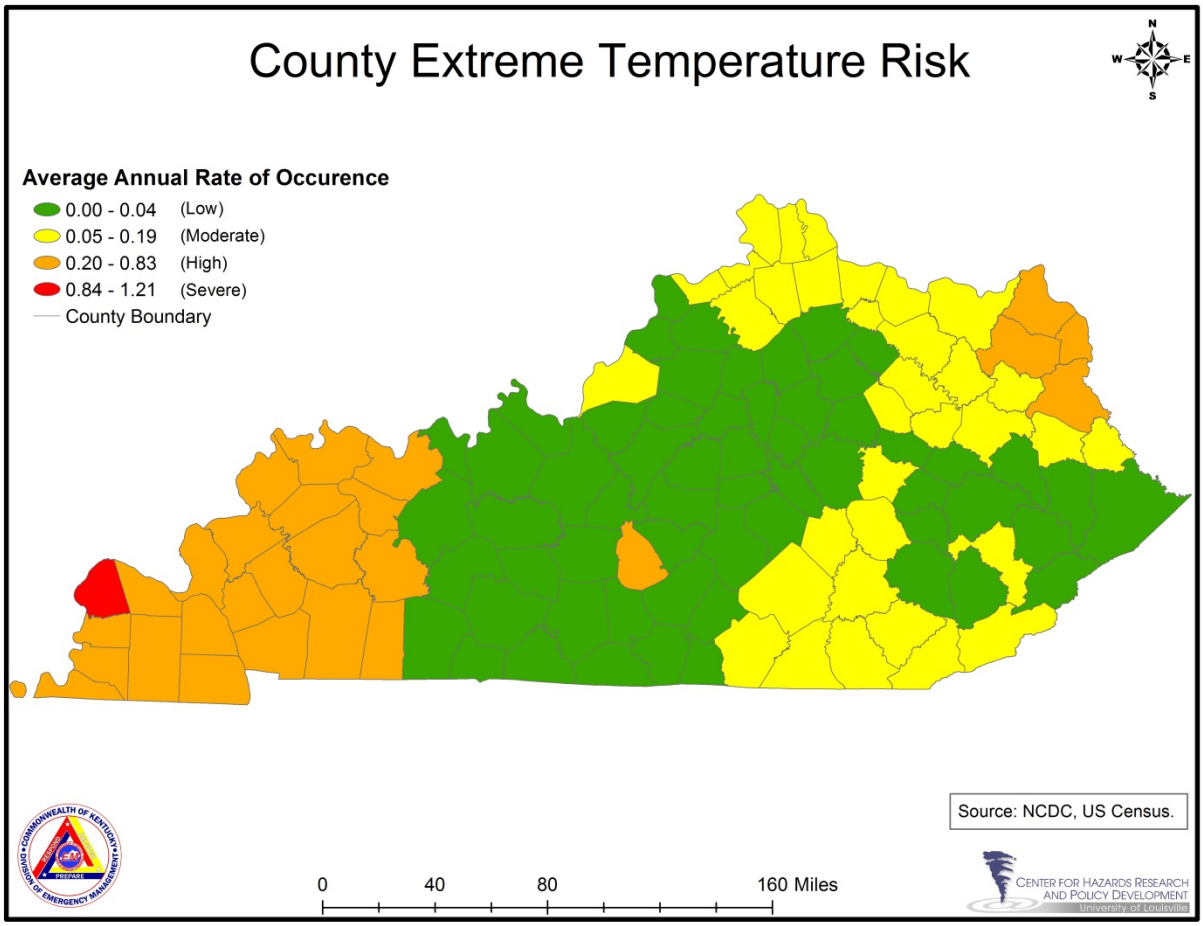
Source: Exposure- Division of State Risk and Insurance, ESRI, Kentucky Infrastructure Authority, Kentucky Office of Geographic Information, Kentucky Transportation Cabinet, KYEM, Public Service Commission, and the US Census Bureau. Hazard: NOAA, Sheldus.

0 30 60 120 Miles

CENTER FOR HAZARDS RESEARCH AND POLICY DEVELOPMENT
University of Louisville

County-Level Risk Assessment Model

The Extreme Temperature County Risk Assessment Model was created using the Extreme Temperature Annual Rate of Occurrence data for each county. The annual rate of occurrence is calculated by dividing the range of years the data has been captured by each county's total number of occurrences (See ***Appendix 3-2*** "Hazard Average Annualized Loss"). This data was then joined to a county map for display as seen below.



The County-Level Risk Assessment Model should be used to compare county-level risk. This data depicts which counties are experiencing the most occurrences of extreme temperature comparatively across Kentucky.

Hail Storm

Identifying Hazards: Hail

Description

Hail is a type precipitation which is formed when updrafts in thunderstorms carry raindrops into extremely cold areas of the atmosphere and freezes them. These frozen raindrops grow by colliding with super-cooled water drops creating 'hailstones'. Thunderstorms which have a strong updraft keep lifting the hailstones up to the top of the cloud, increasing the amount of moisture they collect. The hail falls when the thunderstorm's updraft can no longer support the weight of the ice. The stronger the updraft, the larger the hailstone can grow.

Though Florida has the most thunderstorms, Nebraska, Colorado, and Wyoming usually have the most hail storms. The area where these three states meet – "hail alley," averages seven to nine hail days per year. The reason why this area gets so much hail is that the freezing levels (the area of the atmosphere at 32 degrees or less) in the high plains are much closer to the ground than they are at sea level, where hail has plenty of time to melt before reaching the ground. Other parts of the world that experience damaging hailstorms include China, Russia, India and northern Italy.

When viewed from the air, it is evident that hail falls in paths known as hail swaths. They can range in size from a few acres to an area 10 miles wide and 100 miles long. Piles of hail in hail swaths can be so deep, that snow plows are need to clear roadways, and occasionally, hail drifts have been reported.

Types

Hail is commonly associated with severe storms. While severe storms and super cell storms usually produce the most damaging hail occurrences, many non-super cell storms have produced golf ball size hail. Storms which produce hail are more frequent during the late spring and early summer months.

Although there is no scientific classification of hail, NOAA provides the following comparisons to identify hail sizes with common items.

NOAA Hail Size Comparison	
Non-Severe Sizes	
Pea	¼ inch diameter
Marble	½ inch diameter
Severe Sizes	
Dime/Penny	¾ inch diameter
Nickel	7/8 inch diameter
Quarter	1 inch diameter
Ping-Pong Ball	1 ½ inch diameter
Golf Ball	1 ¾ inch diameter
Tennis Ball	2 ½ inch diameter
Baseball	2 ¾ inch diameter
Tea Cup	3 inch diameter
Grapefruit	4 inch diameter
Softball	4 ½ inch diameter

It is important to note that the severe designation for hail is based on a 1952 study of the "smallest size of hailstones which cause significant damage at airplane speeds between 200 and 300 mph".

Facts

- The largest and heaviest hailstone recovered in the U.S. fell on July 23, 2010 in Vivian, South Dakota and had a diameter of 8 inches, a circumference of 18.62 inches, and weighed 1 lb 15 oz (1.93 pounds).
- Hailstones can fall at speeds of up to 120 miles an hour.
- In the United States, hail is responsible for nearly $1 billion in damage to crops and property each year.

Impacts

The primary impacts of hail are mainly property and infrastructure damages, including crop damages, and personal injuries. Although extensive damage occurs as a result of hail, the event by itself causes few, if any, additional hazards.

Profiling Hazards: Hail

HAIL STORM PROFILE RISK TABLE	
Period of occurrence:	Frequented with severe storms which are most prevalent in Kentucky from April to June. Severe storms can occur whenever conditions are favorable however. As such, hail can occur at any time of the year, although it is a rarity in off season months.
Number of events: (1960-2013)	4,882*
Annual Rate of Occurrence:	92.11
Warning time:	Prediction of hail as a contained event is very difficult. Providing any warning in advance for a threat of hail relies mostly on tracking storm systems which are capable of producing hail. Assuming hail is a possibility, when severe storms are approaching the best warning for hail is this point in time.
Potential impacts:	Impacts to human life, health, and public safety are possible. Utility damage and failure, infrastructure damage (transportation and communication systems), structural damage, fire, damaged or destroyed critical facilities, and hazardous material releases are additional impacts.
Recorded losses:	$983,340,017
Annualized Loss:	$18,553,585
Extent (Historical):	Date: April 16, 1998 Size: 2.75 inches Damage: $714 M

*Data captured from SHELDUS 10.1 (occurrence data captures county-level events across the state)

SIGNIFICANT RECENT HAIL EVENTS IN KENTUCKY				
Date	Location (County)	Magnitude	Property Damage	Crop Damage
5/3/1996	Jefferson	2.75 in	$30 M	0
4/16/1998	Warren	2.75 in	$714 M	0
5/01/2002	Laurel	4.5 in	$38 M	$2.5 M
5/01/2002	Pulaski	4.5 in	$6.3 M	$1.3 M
5/01/2002	Rockcastle	2.75 in	$5.7 M	$1.3 M
5/04/2003	McCracken	2.5 in	$25 M	0
5/04/2003	Marshall	2.75 in	$12.5 M	0
3/2/2012	Wolfe	3.0 in	$2 M	0
3/2/2012	Adair	1.75 in	$1.5 M	0
4/28/2012	Jefferson	2.0 in	N/A	N/A

Data obtained from SHELDUS and NOAA NCDC; adjusted for 2012 inflation

The effects of hailstorms range from minimal to severe damage to anything from personal property to community infrastructure. According to SHELDUS and NOAA NCDC data, there have been no documented deaths or injuries over the past three (3) years from hailstorms in the state of Kentucky. However, there has been over $5.5 million in property damages and over $3,000 in crop damages in the state during that time. As can be seen in the previous table, there were only two (2) hail events that resulted in significant damages of over one million dollars in the past three (3) years.

Hail events occur in all regions of the state and the amount of large hail events (hail with a diameter of 0.75 inches or greater, as specified by the NOAA/NWS Storm Prediction Center) varies greatly by county across the state. Reporting also varies greatly across the state with more populated counties reporting higher numbers of events. This is due to the fact hail events in a more populated county will not only be more noticed, but will also likely cause more damage than a less populated county. The result of this is slightly skewed data, which is also the case with other severe storm events.

There have been numerous instances in Kentucky that demonstrate the destructive capacity of hailstorms. On April 16, 1998 a severe line of storms passed through Adair, Warren, Barren, and Metcalfe counties in Kentucky. This storm system created hail in some areas which was recorded as baseball-size. The city of Bowling Green was devastated by the massive amounts of hail falling from the line of storms. There were 8,300 homes, 900 mobile homes, 4,000 vehicles, 37 businesses, and 14 apartments that sustained major damage. Minor damage was reported for 1,300 homes, 6,000 vehicles, 42 business, and 4 churches. The total damage in the Micropolitan Statistical Area was estimated at $510 million. Additionally, several people received minor injuries after being struck by falling hail.

On May 1, 2002, another severe thunderstorm system that produced at least baseball-sized hail moved across central Kentucky impacting ten counties. Three (3) injuries were reported in Washington County as a result of the hail and softball-size hail was reported in Nelson, Marion, Lincoln, and Pulaski counties, which caused considerable damage to many homes and vehicles. The entire event resulted in approximately $40 million in property damages and $4 million in crop damages across Kentucky.

One of the most devastating hailstorms in Kentucky history occurred on April 28, 2012 in the Louisville metropolitan area. A cluster of severe storms produced one predominate storm that grew into a high precipitation supercell. Hailstones baseball-size and smaller devastated the roofs of residential and commercial properties, and automobiles, both personal and dealerships, were severely impacted. Over five thousand residences also lost power during the deluge. Total damages were estimated at over $175 million dollars in insured losses.

Assessing Vulnerability by Jurisdiction: Hail Storm

Grid-Level Risk Assessment Model

Hail Storm Vulnerability Score = Exposure Score + Hazard Score

Assessing Kentucky's vulnerability to Hail Storm was determined through first calculating the Hail Storm Hazard Score. The Hail Storm Hazard Score was calculated by studying one (1) specific source of data. The data layer used to create the Hail Storm Hazard Score was collected from the National Weather Service NEXRAD Level-III Radar data. The radar data provided a new and improved capture of hail occurrences using radar to capture when and where hail events were occurring from 2000-2012. As with all new technologies this data does come across with some caveats. Currently the radar is not 100% accurate when capturing images so the data comes with probabilities assigned to each data point captured. For this process CHR used anything with a 50% or greater probability as a counted hail occurrence.

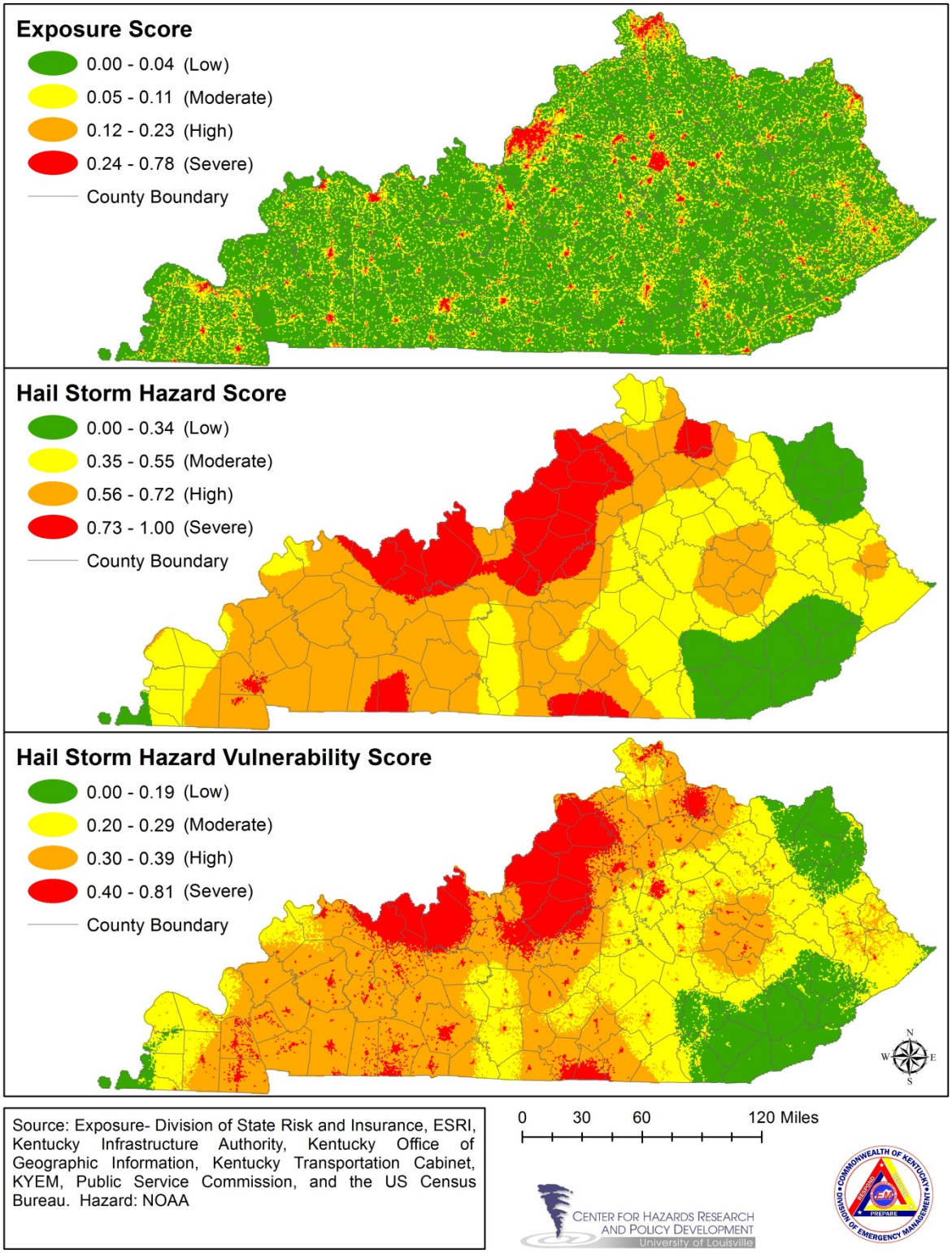
For analyzing this data CHR used a 25 mile radius to calculate each 1 KM MGRS grids geographic risk from a hail event. The 25-mile radius was selected because that is the distance that the National Weather Service uses when producing severe weather alerts and probability maps. Basically, the 25 mile radius reduces the white noise and randomness present in atmospheric event data, which enables a meaningful picture of the risk to each grid, built based on historic rates of occurrence in the area. These 25 mile radiuses create map layers that were used as the base map layer for Hail Storm Hazard Score.

To analyze Kentucky's risk to Hail Storm, the county 25 mile radius Hail Storm layer was overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based on the total number of hail events that occurred within a 25 mile radius of each grid. Each grid was then calculated and scored 0-1 to develop the Hail Storm Hazard Score.

The Hail Storm Vulnerability Score was calculated for each 1 KM MGRS grid by adding each grid's Exposure Score by its Hail Storm Hazard Score and then scored 0-1. Once the final Hail Storm Vulnerability Scores were calculated the composite scores were broken into four (4) categories, using the Natural Breaks classification system (1. Low, 2. Moderate, 3. High, 4. Severe), which demonstrates different levels of vulnerability displayed on the map.

The Grid-Level Risk Assessment Model should be used to identify specific areas of vulnerability located throughout Kentucky. This model provides 106,178 equal areas of comparison for the end users to assess hazard vulnerability. The best way to view and use this data is through a GIS viewer.

The following map displays the maps and components of the Hail Storm Vulnerability Score.



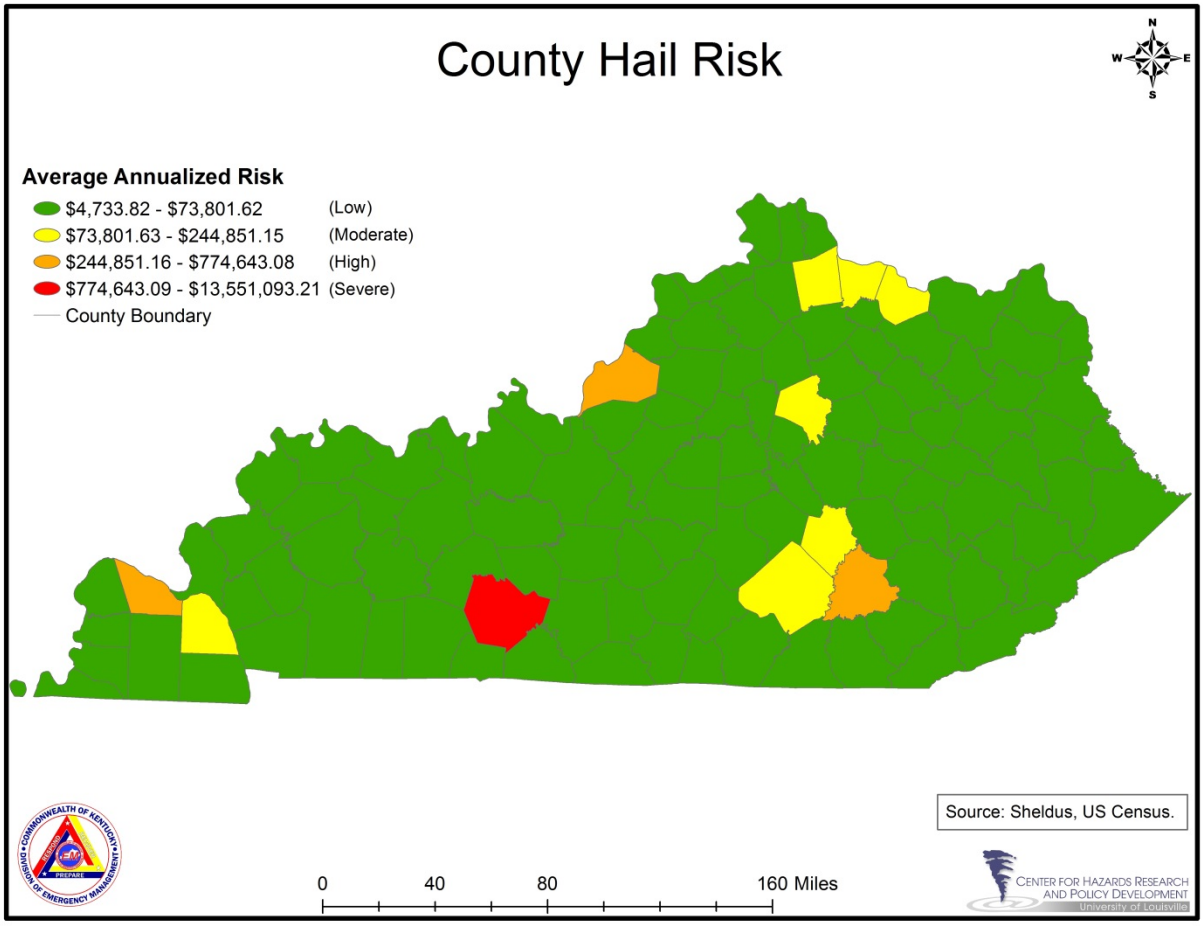
Source: Exposure- Division of State Risk and Insurance, ESRI, Kentucky Infrastructure Authority, Kentucky Office of Geographic Information, Kentucky Transportation Cabinet, KYEM, Public Service Commission, and the US Census Bureau. Hazard: NOAA

0 30 60 120 Miles

CENTER FOR HAZARDS RESEARCH AND POLICY DEVELOPMENT
University of Louisville

County-Level Risk Assessment Model

The Hail Storm County Risk Assessment Model was created using the Hail Storm Average Annual Loss data for each county. The average annual loss is calculated by multiplying each county's annual rate of occurrence by their average losses (See ***Appendix 3-2*** "Hazard Average Annualized Loss"). This data was then joined to a county map for display as seen below.



The County-Level Risk Assessment Model should be used to compare county-level risk. This data depicts which counties are experiencing the most occurrences and losses from hail storms comparatively across Kentucky.

Severe Storm

Identifying Hazards: Severe Storm

Description

A thunderstorm is formed from a combination of moisture, rapidly rising warm air, and a force capable of lifting air such as a warm or cold front, a sea breeze, or a mountain. All thunderstorms contain lightning and may occur singly, in clusters, or in lines. Thus, it is possible for several thunderstorms to affect one location in the course of a few hours. Some of the most severe weather occurs when a single thunderstorm affects one location for an extended period time.

Lightning is an electrical discharge that results from the buildup of positive and negative charges within a thunderstorm. When the buildup becomes strong enough, lightning appears as a "bolt." This flash of light usually occurs within the clouds or between the clouds and the ground. A bolt of lightning reaches a temperature approaching 50,000 degrees Fahrenheit in a split second. The rapid heating and cooling of air near the lightning causes thunder.

Types of Thunderstorms

- *Single Cell (pulse storms).* Typically last 20-30 minutes. Pulse storms can produce severe weather elements such as downbursts, hail, some heavy rainfall and occasionally weak tornadoes. This storm is light to moderately dangerous to the public and moderately to highly dangerous to aviation.
- *Multicell Cluster*. These storms consist of a cluster of storms in varying stages of development. Multicell storms can produce moderate size hail, flash floods and weak tornadoes. This storm is moderately dangerous to the public and moderately to highly dangerous to aviation.
- *Multicell Line*. Multicell line storms consist of a line of storms with a continuous, well developed gust front at the leading edge of the line. Also known as squall lines, these storms can produce small to moderate size hail, occasional flash floods and weak tornadoes. This storm is moderately dangerous to the public and moderately to highly dangerous to aviation.

Tornadic supercell near Owensboro, KY, October 18, 2007.
Source: Accuweather.com. Retrieved: May 1, 2013.

- *Supercell*. Even though it is the rarest of storm types, the supercell is the most dangerous because of the extreme weather generated. Defined as a thunderstorm with a rotating updraft, these storms can produce strong downbursts, large hail, occasional flash floods, and weak to violent tornadoes. This storm is extremely dangerous to the public and aviation.
- *Storms with Straight-line Winds.* Straight-line winds are convective wind gusts, outflow and downbursts that are produced by the downward momentum in the downdraft of a thunderstorm. An environment conducive to strong straight-line wind is one in which the updrafts and thus downdrafts are strong, the air is dry in the middle troposphere and the storm has a fast forward motion If these winds meet or exceed 58 miles per hours then the storm is classified as severe by the National Weather Service.

Types of Lightning

Overall, there are four different types of lightning:

1. *Cloud to Air.* Lightning that occurs when the air around a positively charged cloud top reaches to the negatively charged air around it.
2. *Cloud to ground.* Lightning that occurs between the cloud and the ground.
    - *Bolt from the blue.* A positive lightning bolt which originates within the updraft of the storm, typically 2/3rds of the way up, travels horizontally for many miles, then strikes the ground.
    - *Anvil Lightning.* A positive lightning bolt which develops in the anvil, or top of the thunderstorm cloud, and travels generally straight down to strike the ground.
3. *Intra-cloud.* The most common type of lightning which happens completely inside the cloud, jumping between different charge regions in the cloud. This is sometimes called sheet lightning because it lights up the sky with a 'sheet' of light.
4. *Inter-cloud.* Lightning that occurs between two or more separate clouds.

Lightning flashes can have more than one ground point. Roughly, there are five to ten times as many cloud flashes, or flashes that do not strike the surface, than cloud to ground flashes. They may be inside a cloud, travel from one part of a cloud to another, or from cloud to air.

Thunderstorm and Lightning Facts

- The NWS estimates more than 100,000 thunderstorms worldwide each year.
- 1,800 to 2,000 thunderstorms occur worldwide in a given second.
- In the last 25 years, severe storms have been associated with over 300 federal disaster declarations
- Lightning is the second most frequent killer in the U.S. with nearly 100 deaths and 500 injuries each year.
- Lightning is a component of all thunderstorms.
- In the continental U.S. there are more than 40 million cloud to ground lightning flashes each year.
- The longest bolt, seen to date, was 118 miles long in the Dallas-Ft. Worth, TX area.
- The peak temperature of lightning is around 60,000 degree Fahrenheit, or about 5 times hotter than the surface of the Sun.
- Lightning most commonly occurs in thunderstorms, but it can also occur in snowstorms, sandstorms, and in the ejected material over volcanoes.
- Cloud to ground lightning can injure or kill people and destroy objects by direct or indirect means. Objects can either absorb or transmit energy. The absorbed energy can cause the object to explode, burn, or totally destruct. The various forms of transfer are:
    - Tall object transferred to person
    - Tall object to ground to person
    - Object (telephone line, plumbing pipes) to a person in contact with the appliance

Dangers Associated with Thunderstorms

- Lightning
- Flash floods
- Hail
- Outflow
- Tornadoes
- Winds
- Downbursts or strong down drafts which can cause an outburst of potentially damaging winds at or near the ground
- Micro or macro-bursts

Effects of Lightning

- Fires may occur in structures such as storage and processing units, aircraft, and electrical infrastructure and components.
- Forest fires may be initiated by lightning. Half the wildfires in the western U.S. are caused by lightning.
- Injury and death to people
- 85% of lightning victims are children and young men ages 10 to 35.
- 25% of victims die and 70% of survivors suffer long term effects

Profiling Hazards: Severe Storm

SEVERE STORM PROFILE RISK TABLE	
Period of occurrence:	Spring, Summer, and Fall
Number of events: (1960-2013)	21,481*
Annual Rate of Occurrence:	405.30
Warning time:	Minutes to hours
Potential impacts:	Utility damage and outages, infrastructure damage (transportation and communication systems), structural damage, fire, damaged or destroyed critical facilities, and hazardous material releases. Impacts human life, health, and public safety.
Recorded losses:	$898,499,257*
Annualized Loss:	$16,952,816
Extent (Historical):	Date: September 14, 2008 Scale: 68 knots (kts.) Damages: $168 M property, $69 M crop, 1 death, 46 injuries

*Data captured from SHELDUS 10.1 (occurrence data captures county-level events across the state)

Kentucky is affected every year by severe thunderstorm systems which move across the region. As the above chart demonstrates, Kentucky has experienced 12 presidentially declared disaster events since 2005. Most recently, the March 2, 2012 tornado outbreak resulting from supercells that swept eastward across the Ohio and Tennessee Valleys, were accompanied by strong straight-line winds that, according to the NCDC Storm Events Database, caused an estimated $834,000 in property damage. Five years prior, in September 2008, Kentucky experienced a rare weather event which was of hurricane origin. This system, along with an upper level trough and a surface cold front approaching the region, combined to bring very strong surface wind gusts to the area. Widespread damage occurred with measured wind gusts up to 75 mph, along with seven (7) known injuries and two (2) fatalities across parts of central Kentucky. Seventy-five percent of all Louisville Metro electrical customers - more than 300,000 homes and businesses - lost power for up to a week due to the storm, leaving many businesses and schools closed during the week. Statewide, nearly 600,000 customers lost power due to the storm. Cost estimates were reported as approximately $10 million across the Commonwealth, including $4.2 million in the Louisville Metro area alone. In Kentucky, 33 counties were declared major disaster areas by President Bush.

Severe Storm-related Presidential Disaster Declarations 2005-2013																		
Disaster Declaration	Incident Period	Individual Assistance Applications*	Amount Disbursed*	Total Public Assistance Grants**	Dam Failure	Drought	Earthquake	Extreme Temp.	Flood	Hailstorm	Karst/Sinkhole	Land/Mine	Landslide	Severe Storm	Severe Winter	Tornado	Forest Fire
DR-4057	February 29- March 3, 2012	5,746	$ 10,378,250	$ 12,438,032					x					x		x	
DR-4008	June 19 - 23, 2011	820	$ 2,886,169	$ 2,428,630					x					x		x	
DR-1976	April 12- May 20, 2011	2,330	$ 9,239,830	$ 31,886,410					x					x		x	
DR-1925	July 17-30, 2010	2,548	$ 10,602,929	$ 6,372,211					x				x	x			
DR-1912	May 1, 2010	7,343	$ 20,784,629	$ 22,522,805					x				x	x			
DR-1841	May 3-20, 2009	5,543	$ 15,117,446	$ 34,825,014					x				x	x		x	
DR-1802	September 14-15, 2008	not requested	not requested	$ 18,821,452										x			
DR-1855	August 4, 2008	12,406	$ 17,701,502	$ 3,791,750					x					x			
DR-1757	April 3-4, 2008	not requested	not requested	$ 3,499,938					x				x	x		x	
DR-1746	February 5-6, 2008	1,032	$ 1,466,605	$ 4,954,738					x					x		x	
DR-1617	December 1, 2005	399	$ 459,715	not requested										x		x	

*Source: KY Division of Emergency Management, Recovery Branch. IA Disaster Summary by County.
**Source: FEMA.gov

The following narrative provides more detailed information on severe storms that resulted in Presidential Declarations in Kentucky:

- **November 15, 2005 (DR-1617):** A line of powerful storms moved across the western half of Kentucky and southern Indiana during the afternoon. The line of storms was responsible for damaging winds and a few tornadoes along and west of Interstate 65.

- **February 5-6, 2008 (DR-1746)**: More than $4.5 million in federal disaster public assistance was approved in association with tornadoes and severe storms. The intense thunderstorms and tornadoes resulted in seven (7) fatalities, widespread damages to public and private property, power outages, and road closures. This line of severe weather ran from southwest to northeast spawning 22 tornadoes in 17 counties across western and central Kentucky. In addition to the public assistance grants made available to governmental units and qualifying non-profit entities, this declaration provided assistance to individuals and households in the amount of $1.4 million dollars.

- **April 3-4, 2008 (DR-1757):** During this event the Commonwealth was impacted by severe thunderstorms which produced tornadoes, floods, flash floods, hail, mudslides, and landslides. This line of severe weather resulted in the loss of life and personal injury, power outages, downed trees, road closures, and widespread damage to public and private property. Records show that four (4) to six (6) inches of rain fell in a 24-hour period, with some locally higher observations exceeding eight (8) inches. The heavy rains caused widespread flash flooding, road closures, evacuations, stranded motorists, vehicle-related water rescues, and mudslides. Power outages were reported throughout the Commonwealth for several days due to damages or power being shut off as a safety measure. Waters remained high along rivers through mid-April. A number of communities resorted to sandbagging to protect homes and schools from flooding and the continuing rising waters.

- **September 14, 2008 (DR-1802):** On this date the remnants of Hurricane Ike, strengthened by a cold front crossing the Ohio Valley, caused extremely strong surface winds to blow across the Commonwealth resulting in widespread damage to public and private property and affecting 1.8 million residents. Hurricane-force wind gusts caused an immense number of trees to fall and power outages in numerous counties of the Commonwealth, leaving citizens in the dark and without essential services for weeks after the storm. A total of $168 M in property damage was recorded, $69 M in crop damage, and 1 death and 46 injuries were recorded.

- **May 3 - 20, 2009 (DR-1841):** Starting on May 3, 2009, strong storms producing tornadoes, severe thunderstorms, heavy rainfall, flash flooding, and generalized flooding moved across the central and eastern parts of the Commonwealth resulting loss of live and private property and road closures and these conditions endangered public health and safety and threatened public and private property. There were over half a million citizens impacted by this event.

- **August 14, 2009 (DR-1855):** On August 14, 2009, the counties of Jefferson and Trimble experienced a severe storm which contained straight-line winds and flooding. The flooding in Louisville was centralized in the downtown resulting in significant damages to the University of Louisville, the Louisville Public Library, several hospitals, and over a thousand private residences. Public Assistance is estimated to exceed $27 million dollars and over $17 million has been distributed in individual and household assistance.

- **May 11, 2010 (DR-1912):** Beginning on Derby Day, May 1, 2010, the Commonwealth was inundated with a severe rain event as was also Tennessee. Flooding which occurred across Kentucky was exacerbated by massive flooding in Tennessee rivers (the Cumberland and Tennessee) which flow into Kentucky. Eighty-four Kentucky counties were impacted by this disaster which was declared by President Obama on May 11, 2010.

- **July 17-30, 2010 (DR-1925):** On the night of July 18, an isolated severe thunderstorm caused widespread tree and power damage across southeastern Kentucky. The major damage resulted from flash flooding beginning on July 17. See the "Flood" profile section for additional information on this event.

- **April 12-May 20, 2011 (DR-1976):** During an incident period of over one month, NCDC recorded $4.183 million in property damage across 94 County/Zone affected areas. One of the most costly of severe storm events recorded, occurred on April 25th in Calloway County where wind gusts were measured at 101 mph a number of buildings were damaged and an industrial warehouse was destroyed. There was extensive damage to trees and power lines in the city of Murray. Property damage in this county totaled $2 million. On this same day, an EF3 tornado hit Christian County caused $1 million in damage.

- **June 19-23, 2011 (DR-4008):** The June 18-22 tornado outbreak lasted five (5) days and produced widespread tornado activity; five tornadoes of which struck the Louisville metropolitan area, along with widespread damaging winds. While tornado and flood damage was substantial (see "Tornado" and "Flood" profile section for additional information on this event) trees and utilities were reported down, along with widespread damage to buildings in Bell, Breathitt, Knott, Knox, Lee, Magoffin, and Perry Counties.

- **March 2, 2012 (DR-4057):** A deadly tornado outbreak occurred over a large section of the southern U.S. into the Ohio Valley region. Between 1:38 p.m. and 7:25 p.m. 27 Kentucky counties experienced $33.489 million in damage with 23 deaths and 207 injuries. These tornado outbreaks resulting from supercells that swept eastward across the Ohio and Tennessee Valleys were accompanied by strong straight-line winds that, according to the NCDC Storm Events Database, caused an estimated $834,000 in property damage. For more information about this disaster view "Tornado" profile.

Assessing Vulnerability by Jurisdiction: Severe Storm

Grid-Level Risk Assessment Model

Severe Storm Vulnerability Score = Exposure Score + Hazard Score

Assessing Kentucky's vulnerability to Severe Storm was determined through first calculating the Severe Storm Hazard Score. The Severe Storm Hazard Score was calculated by studying two (2) specific sources of data. The two (2) data layers used to create the Severe Storm Hazard Score were collected from the National Weather Service SVRGIS wind point (1955-2012) and wind swath (2006-2012) GIS data layers. This GIS point data was combined to create the baseline for the Severe Storm Hazard Score.

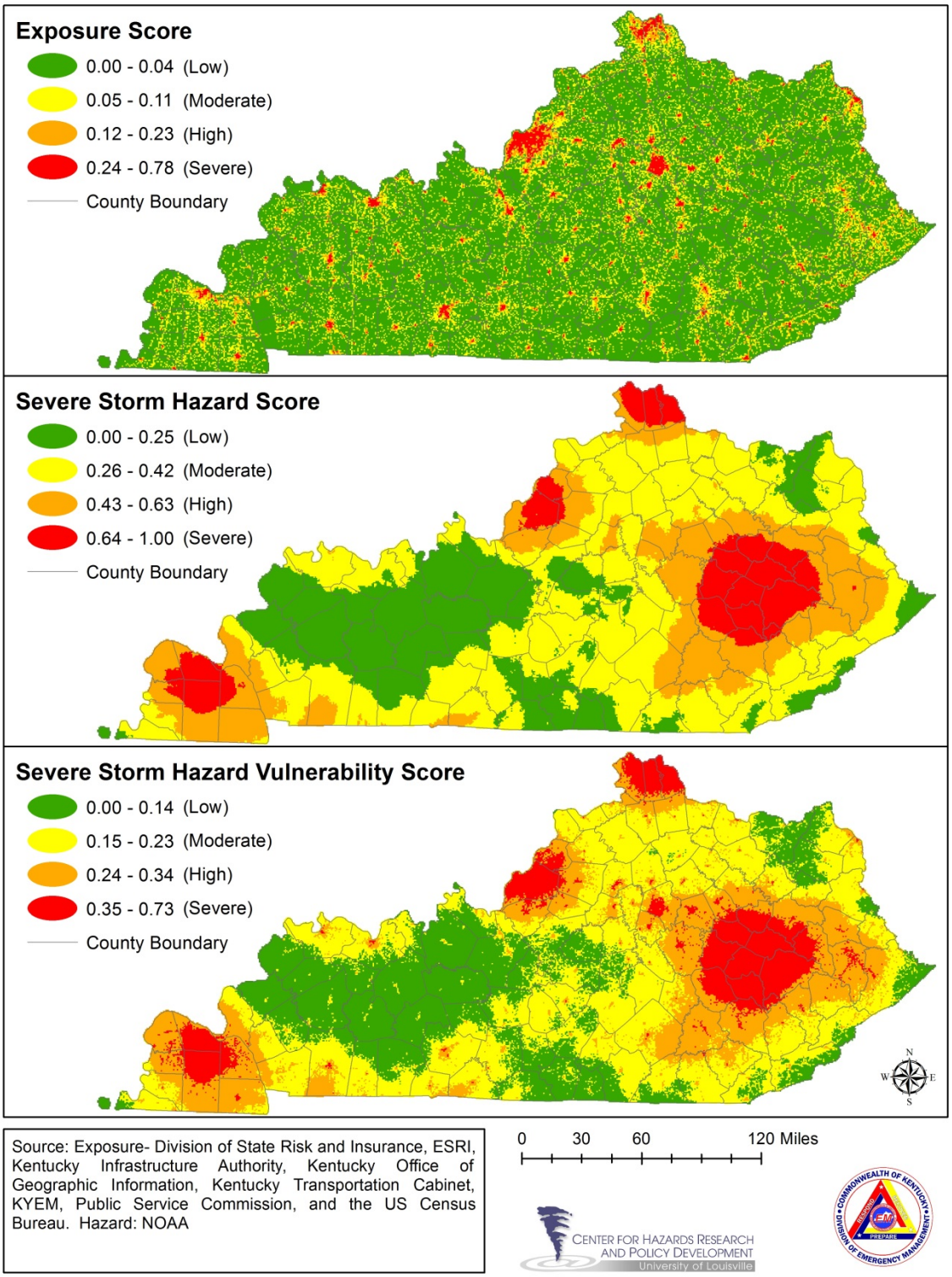
For analyzing this data CHR used a 25 mile radius to calculate each 1 KM MGRS grids geographic risk from a severe storm event. The 25-mile radius was selected because that is the distance that the National Weather Service uses when producing severe weather alerts and probability maps. Basically, the 25 mile radius reduces the white noise and randomness present in atmospheric event data, which enables a meaningful picture of the risk to each grid, built based on historic rates of occurrence in the area. These 25 mile radiuses create map layers that were used as the base map layer for Severe Storm Hazard Score.

To analyze Kentucky's risk to Severe Storm, the county 25 mile radius Severe Storm layer was overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based on the total number of severe storm events that occurred within a 25 mile radius of each grid. Each grid was then calculated and scored 0-1 to develop the Severe Storm Hazard Score.

The Severe Storm Vulnerability Score was calculated for each 1 KM MGRS grid by adding each grid's Exposure Score by its Severe Storm Hazard Score and then scored 0-1. Once the final Severe Storm Vulnerability Scores were calculated the composite scores were broken into four (4) categories, using the Natural Breaks classification system (1. Low, 2. Moderate, 3. High, 4. Severe), which demonstrates different levels of vulnerability displayed on the map.

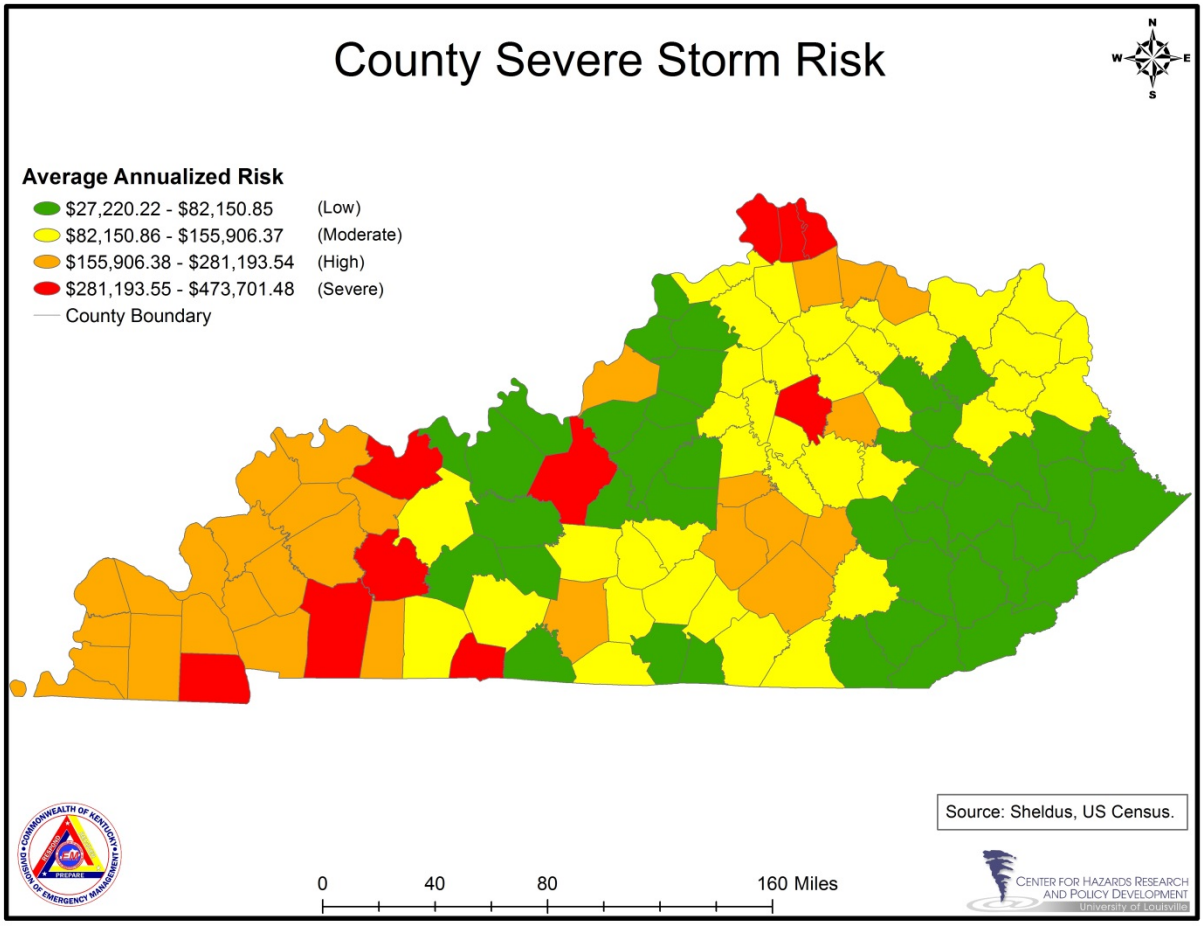
The Grid-Level Risk Assessment Model should be used to identify specific areas of vulnerability located throughout Kentucky. This model provides 106,178 equal areas of comparison for the end users to assess hazard vulnerability. The best way to view and use this data is through a GIS viewer.

The following map displays the maps and components of the Severe Storm Vulnerability Score.



County-Level Risk Assessment Model

The Severe Storm County Risk Assessment Model was created using the Severe Storm Average Annual Loss data for each county. The average annual loss is calculated by multiplying each county's annual rate of occurrence by their average losses (See Appendix 2X "Hazard Average Annualized Loss"). This data was then joined to a county map for display as seen below.



The County-Level Risk Assessment Model should be used to compare county-level risk. This data depicts which counties are experiencing the most occurrences and losses from severe storms comparatively across Kentucky.

Severe Winter Storm

Identifying Hazards: Severe Winter Storm

Description

A winter storm can range from moderate snow over a few hours to blizzard conditions with blinding wind-driven snow, sleet and/or ice that lasts several days. Some winter storms may be large enough to affect several states while others may affect only a single community. All winter storms are accompanied by low temperatures and blowing snow, which can severely reduce visibility. A severe winter storm is defined as an event that drops four (4) or more inches of snow during a 12-hour period or six (6) or more inches during a 24 hour span. All winter storms make driving and walking extremely hazardous. The aftermath of a winter storm can impact a community or region for days, weeks, or months.

Types

- *Blizzards* are by far the most dangerous of all winter storms. They are characterized by temperatures below twenty degrees Fahrenheit and winds of at least 35 miles per hour. In addition to the temperatures and winds, a blizzard must have a sufficient amount of falling or blowing snow. The snow must reduce visibility to one-quarter mile or less for at least three (3) hours. With high winds and heavy snow, these storms can punish residents throughout much of the U.S. during the winter months each year. In Mid-March of 1993, a major blizzard struck the Eastern U.S., including parts of Kentucky.
- *Ice storms* occur when freezing rain falls from clouds and freezes immediately on impact. Ice storms occur when cold air at the surface is overridden by warm, moist air at higher altitudes. As the warm air advances and is lifted over the cold air, precipitation begins falling as rain at high altitudes then becomes super cooled as it passes through the cold air mass below, and, in turn, freezes upon contact with chilled surfaces at temperatures of 32º F or below. In extreme cases, ice may accumulate several inches thick, though just a thin coating is often enough to do severe damage. In January 2009, a massive ice storm impacted the center U,S. including Kentucky.

Facts

Storm effects such as power outages, extreme cold, flooding, and snow accumulation can cause hazardous conditions and hidden problems, including the following:

- *Power outages* can result when snow and ice accumulation on trees cause branches and trunks to break and fall onto vulnerable power lines. Blackouts vary in size from one street to an entire city.
- *Extreme cold temperatures* may lead to frozen water mains and pipes, damaged car engines, and prolonged exposure to cold resulting in frostbite.
- *Flooding* may occur after precipitation has accumulated and then temperatures rise once again which melts snow and ice. In turn, as more snow and ice accumulate, the threat of flooding increases.
- *Snow and ice accumulation on roadways* can cause severe transportation problems in the form of extremely hazardous roadway conditions with vehicles losing control, collisions, and road closures.

Typical winter storm, Louisville, Kentucky

Profiling Hazards: Severe Winter Storm

SEVERE WINTER STORM PROFILE RISK TABLE	
Period of occurrence:	Winter
Number of events: (1960-2013)	3,951*
Annual Rate of Occurrence:	74.55
Warning time:	Days for Snow Minutes to hours for ice
Potential impacts:	Power outages, which results in loss of electrical power and potentially loss of heat, and human life. Extreme cold temperatures may lead to frozen water mains and pipes, damaged car engines, and prolonged exposure to cold resulting in frostbite
Recorded losses:	$435,706,556*
Annualized Loss:	$8,220,878
Extent (Historical):	Date: January 26 – February 13, 2009 Damages: $307 M, multiple injuries and 36 fatalities Scale: 1.5 inches of ice

*Data captured from SHELDUS 10.1 (occurrence data captures county-level events across the state)

Kentucky's location makes it vulnerable to heavy snowfall. Its proximity to the Gulf of Mexico provides a necessary moisture source for precipitation all year. Kentucky is also north enough to be influenced by polar air masses. Depending on atmospheric conditions during the winter, Kentucky can have cool, wet winter or suffer the ill effects of heavy snow fall and ice accumulation.

Severe Winter Storm-related
Presidential Disaster Declarations
2005-2013

Disaster Declaration	Incident Period	Individual Assistance Applications*	Amount Disbursed*	Total Public Assistance Grants**	Dam Failure	Drought	Earthquake	Extreme Temp.	Flood	Hailstorm	Karst/Sinkhole	Land/Mine	Landslide	Severe Storm	Severe Winter	Tornado	Forest Fire
DR-1818	January 26 - February 13, 2009	not requested	not requested	$213,768,779					x						x		

*Source: KY Division of Emergency Management, Recovery Branch. IA Disaster Summary by County.
**Source: FEMA.gov

As the above chart demonstrates, in early 2009, Kentucky's worst modern day, natural disaster occurred in the form of a severe winter storm. A storm system moving across the Midwest dropped a devastating amount of ice on the state. As rain continued and temperatures fluctuated above and below freezing temperatures, ice formed on all surfaces, several inches thick in some places. Eventually the weight of the ice was too much for trees and utility lines which broke under the tremendous strain.

President Barack Obama declared Kentucky in a state of emergency on January 28, 2009, through Emergency Declaration 3302 and declared disaster DR-1818 on February 5, 2009. After the freezing rain ended, trees and utility lines continued to fall causing extensive damage and power outages. The situation was so severe that 4,600 members of the National Guard were called to Kentucky. They helped to clear debris, deliver food to those without power, as well as tend to people stranded or in need of help. Five thousand utility workers, some from as far away as Texas, worked around the clock to restore power. There were more than 769,000 power outages reported. Many of these outages lasted as long as four weeks in areas which remained difficult to reach because of debris and heavy ice accumulation. As a result of power loss and ineffective preparedness in some areas, 36 deaths were recorded and several injuries occurred due to falling debris and extreme temperatures. Around $616 million worth of damage and loss resulted because of this severe winter storm. As a result of this event, federal assistance was available for 104 of the state's 120 counties.

- **December 18-19, 2009:** A large and intense area of low pressure moved across the Tennessee valley and eventually up to the east coast on December 18th and 19th. The highest snowfall totals for this event were 16 inches on Black Mountain, 13 inches on Flatwood Mountain in Pike County, and 11 inches at the Jackson weather office. Numerous trees and power lines were downed by the heavy wet snow with widespread and long lasting power outages reported across the area.
    - McCreary County ($250,000 in property damage) reported that 37,000 customers were without power as of 2 p.m. on the 19th.
    - Perry County ($50,000 in property damage) reported trees down in the Vicco area and power outages reported in the Woodland section of Hazard.
    - Leslie County ($350,000 in property damage) reported that trees and power lines were down across the county with many secondary roads impassable due to the heavy wet snow.
    - Pike County ($100,000 in property damage) reported that numerous trees and power lines were down across the county.

- **January 26, 2009 – February 13, 2009 (DR-1818):** Ice, snow, and rain paralyzed the Commonwealth. Fallen trees, debris, and power outages left extremely large groups of people, including the elderly and medically fragile, without essential services. Fatalities occurred in multiple counties as a result of this event. Communication services failed cutting off contact with numerous communities. The National Guard was activated and along with emergency workers and law enforcement, thousands of house-to-house checks were performed to identify and rescue those citizens at medical risk. Downed trees necessitated extensive road closures and created power outages that, in some areas, exceeded four (4) weeks. This event represents the largest Commonwealth disaster in modern history.

- **February 3-6, 1998:** A major snowstorm affected 33 counties in eastern Kentucky. Snowfall totals for the storm ranged from around four (4) inches in valley locations near the Virginia border to as much as two (2) feet in other areas. Power outages were widespread as falling trees brought down by the weight of an unusually wet snow disabled utility lines. Nine thousand customers of various utility companies were still without power on February 9, 1998, and some areas were without power for two (2) weeks.

  Numerous roads were blocked by debris. Bulldozers had to be used to reach people who were stranded. Numerous buildings, including trailer homes, houses, barns, and commercial buildings collapsed under the weight of the snow. Many people remained in unheated homes during the extended power outages. A woman in McCreary County died in her home as a result of a hypothermia-induced heart attack. A man in Wolfe County died from similar circumstances.

- **January 8, 1996:** The notorious "Blizzard of 96'" brought a significant amount of snowfall to the Greater Cincinnati/Northern Kentucky area and was the largest 24-hour snowfall on record. Total snowfall from the storm accumulated to 14.3 inches, over half the amount the area receives in an entire season (23 inches). Many homes and businesses experienced partial or total roof collapses due to the weight of the snow. Road conditions remained hazardous in some locations for many days.

- **March 3, 1993:** One of the strongest winter storms ever (it is sometimes referred to as "the storm of the century") dumped 30 inches of snow in some areas of eastern and southeastern Kentucky. The snow accompanied high winds, produced snow drifts from six (6) to 10 feet high. For two days Interstate 75 was closed from Lexington, Kentucky to the Tennessee border. Interstate 64 was closed from Lexington to the West Virginia border. Between 3,000 and 4,000 motorists were stranded along the highways. Some of the heavier snow amounts with respective locations were: 30 inches in Perry County, 24 inches in Pikeville, 22 inches in Ashland, and 22 inches in London.

Assessing Vulnerability by Jurisdiction: Severe Winter Storm

Grid-Level Risk Assessment Model

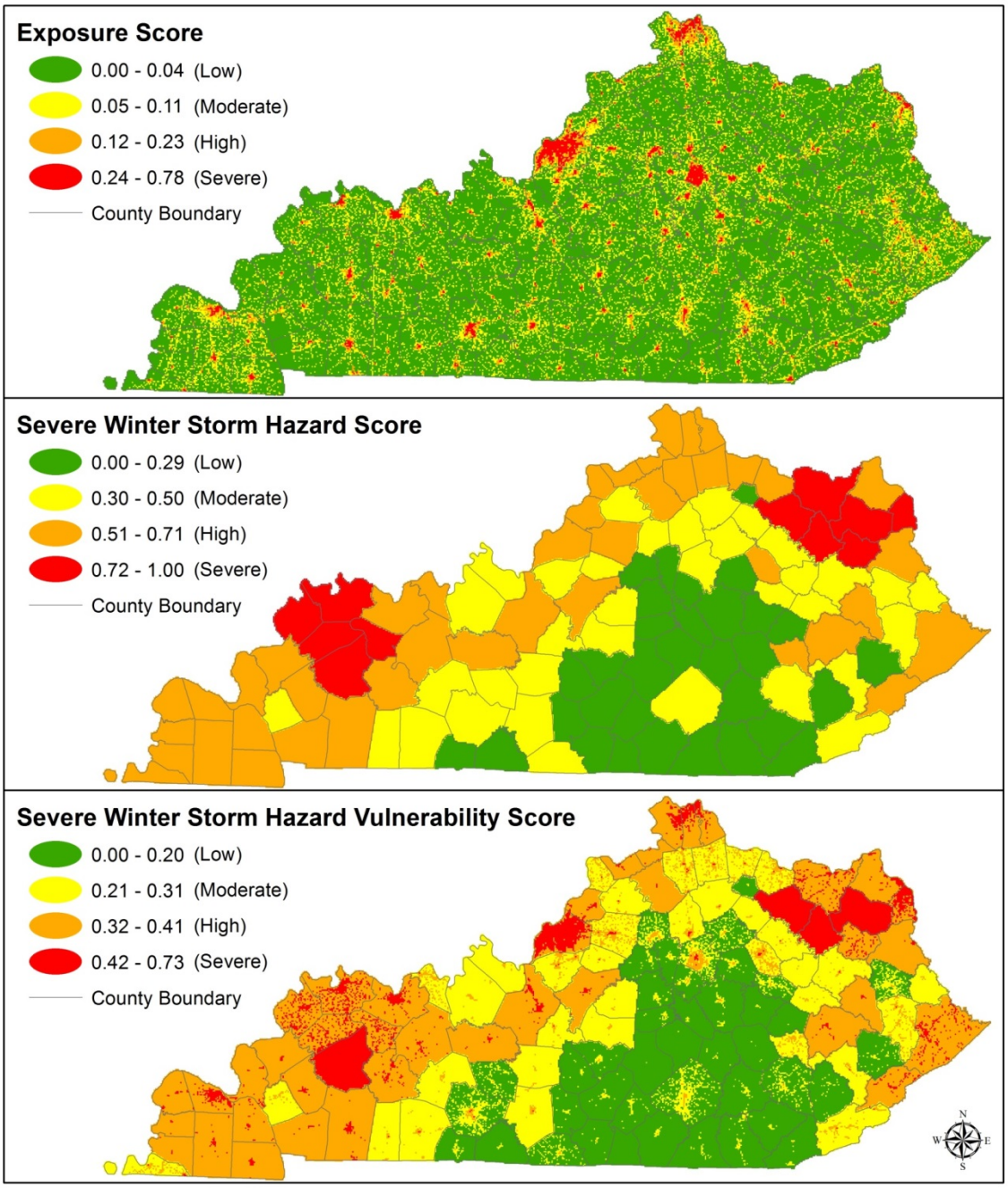
Severe Winter Storm Vulnerability Score = Exposure Score + Hazard Score

Assessing Kentucky's vulnerability to Severe Winter Storm was determined through first calculating the Severe Winter Storm Hazard Score. The Severe Winter Storm Hazard Score was calculated by studying one (1) specific source of data. The data layer used to create the Severe Winter Storm Hazard Score was data collected from the capturing county-level Severe Winter Storm events. In order to use this data for the Severe Winter Storm Hazard Score each county was assigned their maximum number of events and that data was aggregated to each grid within that county. To analyze Kentucky's risk to Severe Winter Storm, the county Severe Winter Storm layer was overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based on the percent of the area the Severe Winter Storm layer covered within each grid. This percentage of area affected by the Severe Winter Storm layer was then calculated and scored 0-1 to develop the Severe Winter Storm Hazard Score.

The Severe Winter Storm Vulnerability Score was calculated for each 1 KM MGRS grid by adding each grid's Exposure Score by its Severe Winter Storm Hazard Score and then scored 0-1. Once the final Severe Winter Storm Vulnerability Scores were calculated the composite scores were broken into four (4) categories, using the Natural Breaks classification system (1. Low, 2. Moderate, 3. High, 4. Severe), which demonstrates different levels of vulnerability displayed on the map.

The Grid-Level Risk Assessment Model should be used to identify specific areas of vulnerability located throughout Kentucky. This model provides 106,178 equal areas of comparison for the end users to assess hazard vulnerability. The best way to view and use this data is through a GIS viewer.

The following map displays the maps and components of the Severe Winter Storm Vulnerability Score.



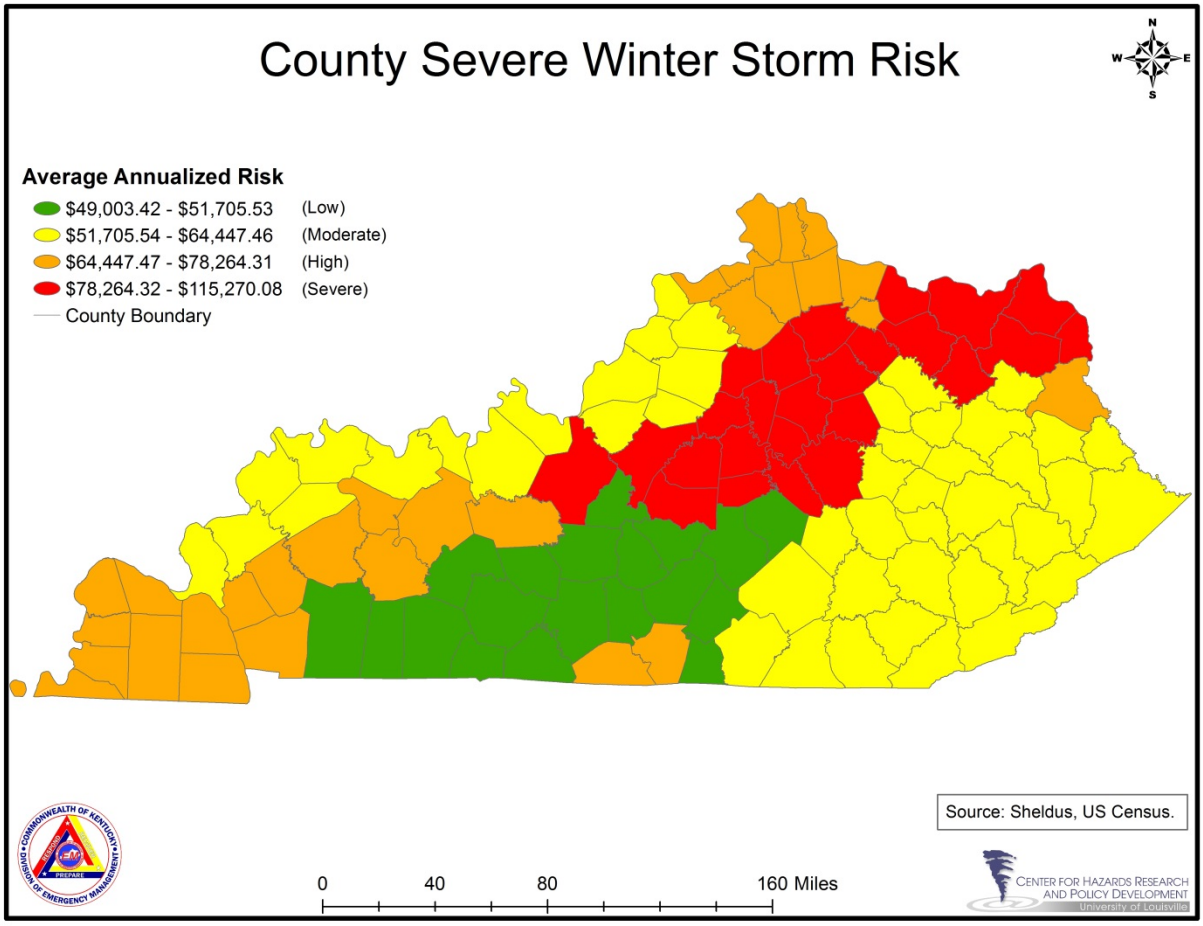
Source: Exposure- Division of State Risk and Insurance, ESRI, Kentucky Infrastructure Authority, Kentucky Office of Geographic Information, Kentucky Transportation Cabinet, KYEM, Public Service Commission, and the US Census Bureau. Hazard: Sheldus

0 30 60 120 Miles

CENTER FOR HAZARDS RESEARCH AND POLICY DEVELOPMENT
University of Louisville

County-Level Risk Assessment Model

The Severe Winter Storm County Risk Assessment Model was created using the Severe Winter Storm Average Annual Loss data for each county. The average annual loss is calculated by multiplying each county's annual rate of occurrence by their average losses (See ***Appendix 3-2*** "Hazard Average Annualized Loss"). This data was then joined to a county map for display as seen below.



The County-Level Risk Assessment Model should be used to compare county-level risk. This data depicts which counties are experiencing the most occurrences and losses from severe winter storms comparatively across Kentucky.

Tornado

Identifying Hazards: Tornado

Description

A tornado is a violent windstorm characterized by a twisting, funnel-shaped cloud. It is spawned by a thunderstorm (or sometimes as a result of a hurricane) and produced when cool air overrides a layer of warm air, forcing the warm air to rise rapidly. The damage from a tornado is a result of the high wind velocity (up to 250 mph) and wind-blown debris with paths that can be in excess of one mile wide and fifty miles long. They have been known to blow off roofs of houses, move cars and tractor trailers, and completely demolish homes. Peak months of tornado activity for are usually April, May, and June. However, tornadoes have occurred in every month and at all times of the year. They tend to occur in the afternoons and evenings; over 80 percent of all tornadoes strike between noon and midnight.

Types

The magnitude of a tornado is categorized by its damage pattern (i.e. path) and its wind velocity, according to the Fujita-Pearson Tornado Measurement Scale. This scale is the only widely used rating method. Its aim is to validate classification by relating the degree of damage to the intensity of the wind.

The Fujita-Pearson Tornado Measurement Scale		
Fujita Scale	Estimated Wind Speed (mph)	Typical Damage
F0	< 73	Light Damage - Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; signboards damaged.
F1	73 - 112	Moderate Damage - Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos blown off roads.
F2	113 - 157	Considerable Damage - Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; light object missiles generated; cars lifted off ground.
F3	158 - 206	Severe Damage - Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.
F4	207 - 260	Devastating Damage - Well-constructed houses leveled; structures with weak foundations blown away some distance; cars thrown and large missiles generated.
F5	261 - 318	Incredible Damage - Strong frame houses leveled off foundations and swept away; automobile-sized missiles fly through the air in excess of 100 meters (109 yards); trees debarked; incredible phenomena will occur.

Facts

- World-wide, approximately 1,000 tornadoes are generated by severe thunderstorms each year.
- Earthquake-induced fires and wildfires may also produce tornadoes.
- A tornado can move as fast as 125 mph with internal winds speeds exceeding 300 mph.
- Powerful tornadoes have lifted and moved objects weighing more than 300 tons a distance of thirty feet and have tossed homes greater than 300 feet away from their foundations.
- During an outbreak from May 4-10 of 2003, 334 tornadoes were recorded.
- In the entire month of May 2003, 559 tornadoes were reported.
- On April 3, 1974, 148 tornadoes in 13 states killed 315 people.
- The path of a tornado can be many miles long, but tornadoes rarely last longer than 30 minutes.
- Tornadoes may cause crop and property damage, power outages, environmental degradation, injury, and death.

Impacts

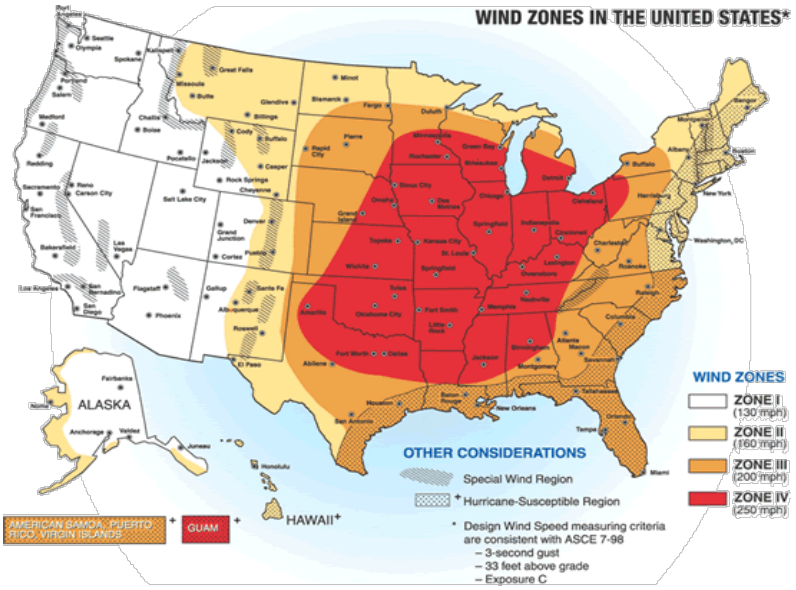
- The primary impacts of tornado outbreaks affect infrastructure and human life most directly. Catastrophic damage may result from tornadoes leaving houses, businesses, and even streets destroyed.
- The secondary impacts of loss of critical infrastructure may result in hazards and additional problems well after a tornado has passed. Citizens may be without shelter, power, or running water for several days, depending on the severity of the tornado.
- Loss of critical infrastructure may also impact local or regional economies by inhibiting transportation of goods and the availability of certain services.

West Liberty, Kentucky, 2012

Profiling Hazards: Tornado

TORNADO PROFILE RISK TABLE	
Period of occurrence:	Spring, Summer, and Fall
Number of events: (1960-2013)	1,136*
Annual Rate of Occurrence:	21.43
Warning time:	Minutes to hours
Potential impacts:	Utility damage and outages, infrastructure damage (transportation and communication systems), structural damage, fire, damaged or destroyed critical facilities, and hazardous material releases. Impacts human life, health, and public safety.
Recorded losses:	$1,020,237,467*
Annualized Loss:	$19,249,764
Extent (Scale):	Date: March 2-3, 2012 Scale: EF4 Damages: $33.5 M, 23 deaths, 207 injuries

*Data captured from SHELDUS 10.1 (occurrence data captures county-level events across the state)



Tornadoes are common throughout Kentucky and historically have occurred in every month of the year. Unfortunately, the occurrence of a tornado is highly unpredictable. Forecasting the exact time and location a tornado will touch down and the path it will take is nearly impossible.

It is possible however to create a valuable risk assessment based on historic occurrences of tornados and the damage resulting from such events. Also, it is important to consider the majority of Kentucky is located in the most severe wind zone (ZONE IV 250 mph) in the country. The state is historically highly vulnerable to tornado-related weather.

Tornado-related Presidential Disaster Declarations 2005-2013																	
Disaster Declaration	Incident Period	Individual Assistance Applications*	Amount Disbursed*	Total Public Assistance Grants**	Dam Failure	Drought	Earthquake	Extreme Temp.	Flood	Hailstorm	Karst/Sinkhole	Landslide/Mine	Landslide	Severe Storm	Severe Winter	Tornado	Forest Fire
DR-4057	February 29- March 3, 2012	5,746	$ 10,378,250	$ 12,438,032					x					x		x	
DR-4008	June 19 - 23, 2011	820	$ 2,886,169	$ 2,428,630					x					x		x	
DR-1976	April 12- May 20, 2011	2,330	$ 9,239,830	$ 31,886,410					x					x		x	
DR-1841	May 3-20, 2009	5,543	$ 15,117,446	$ 34,825,014					x				x	x		x	
DR-1757	April 3-4, 2008	not requested	not requested	$ 3,499,938					x				x	x		x	
DR-1746	February 5-6, 2008	1,032	$ 1,466,605	$ 4,954,738					x					x		x	
DR-1617	December 1, 2005	399	$ 459,715	not requested										x		x	

*Source: KY Division of Emergency Management, Recovery Branch. IA Disaster Summary by County.
**Source: FEMA.gov

West Liberty, Kentucky 2012

As the previous chart demonstrates, since 2005, Kentucky has received Presidential Major Disaster Declarations for seven (7) events that included widespread damage from tornado. To gain a better understanding of the magnitude of tornado impacts on the state, information regarding these and additional tornadic events in Kentucky follows:

March 2, 2012 Tornado Outbreak by County				
County	Magnitude	Deaths	Injuries	Property Damage
Kenton	EF4	4	8	$ 20,000,000.00
Lawrence	EF3	2	8	$ 2,350,000.00
Pendleton	EF3	0	0	$ 2,000,000.00
Magoffin	EF3	0	30	$ 1,800,000.00
Morgan	EF3	6	80	$ 1,600,000.00
Johnson	EF1-3	2	7	$ 1,005,000.00
Campbell	EF3	0	0	$ 1,000,000.00
Laurel	EF2	6	40	$ 815,000.00
Trimble	EF0-3	0	0	$ 625,000.00
Martin	EF2	0	0	$ 547,000.00
Menifee	EF3	2	30	$ 530,000.00
Grant	EF3	0	0	$ 500,000.00
Owen	EF2	0	3	$ 320,000.00
Breckinridge	EF2	0	0	$ 150,000.00
Bracken	EF0	0	0	$ 70,000.00
Henderson	EF0	0	0	$ 50,000.00
Warren	EF1	0	0	$ 50,000.00
Hancock	EF1	0	0	$ 40,000.00
Bath	EF1	0	0	$ 35,000.00
Meade	EF0	0	0	$ 2,000.00
Union	EF2	1	1	$ -
Webster	EF0	0	0	$ -
Daviess	EF0	0	0	$ -
Henry	EF1	0	0	$ -
Wolfe	EF1	0	0	$ -

Source: National Climatic Data Center, Storm Events Database. Retrieved: April 30, 2013.

- **March 2-3, 2012 (DR-4057):** A deadly tornado outbreak occurred over a large section of the southern U.S. into the Ohio Valley region. Between 1:38 p.m. and 7:25 p.m. 27 KY counties experienced $33.5 million in damage with 23 deaths and 207 injuries. The accompanying table shows the amount of damage as recorded by the National Climatic Data Center.

- **February 29, 2012 (DR-4057):** Tornadoes ranging from EF0 to EF2 touched down affecting 13 counties: Ballard ($100,000), McCracken ($150,000, 5 injuries), Henderson ($80,000, 2 injuries), Hopkins ($10,000), Muhlenberg ($130,000, 1 injury), Grayson ($50,000, 1 injury), Hardin ($200,000), Larue ($220,000), Metcalfe ($10,000), Russell ($200,000), Morgan ($100,000), Casey ($10,000), and Pulaski ($50,000).

- **January 17, 2012:** Tornadoes ranging from EF0 to EF2 touched down causing damage in Jefferson ($350,000, 1 injury), Scott ($30,000), Simpson ($75,000), and Allen ($10,000) counties.

- **September 25, 2011:** Isolated tornadoes ranging from EF1 to EF2 touched down causing damage in Hopkins ($80,000) and Christian ($40,000) counties.

- **June 19-23, 2011 (DR-4008):** Tornadoes ranging from EF1 to EF2 touched down in Jefferson county, causing $800,000 in property damage.

- **May 23, 2011:** An EF2 touched down in Lafayette of Christian County, causing $350,000 in property damage and 1 injury.

- **April 23, 2011 (DR-1976):** Tornadoes ranging from EF0 to EF2 affected seven (7) counties: Harrison, Ballard ($100,000), Carlisle ($2 million, 2 injuries), Grant ($55,000), Pendleton ($5,000), and Kenton ($15,000). The brunt of the damage occurred in the downtown area of Bardwell, with several of the damaged buildings deemed a total loss and they had to be demolished. Peak winds were estimated near 120 mph.

- **April 22, 2011 (DR-1976):** Tornadoes ranging from EF0 to EF2 affected four (4) counties: Union ($300,000), Webster ($500,000, 2 injuries), Henderson ($80,000), and Daviess ($3,000).

- **April 4, 2011:** From western to eastern KY, isolated tornadoes ranging from EF0 to EF2 affected 10 counties: Ballard ($740,000, 1 injury), McCracken ($30,000), Muhlenberg ($100,000), Christian ($2 million, 7 injuries), Butler, Grayson, Monroe, Clinton, Whitley ($200,000), and Floyd ($10,000).

- **February 28, 2011:** A NWS storm survey confirmed an EF3 tornado with winds of up to 140 mph in Henry County. Of the largest amount of damage, Henry County rang in at $500,000 and one injury was recorded. Three (3) other counties were affected: Jefferson ($1,000), Lincoln ($100,000), and Wolfe ($75,000).

- **February 24, 2011:** Storms moving across the Lower Ohio Valley produced scattered wind damage and a few tornadoes ranging from EF0 to EF2, affecting four (4) counties: Fulton ($30,000), Hickman ($60,000), Graves ($20,000), and Christian ($600,000).

- **October 26, 2010:** A squall line developed ahead of a cold front that produced widespread damaging wind gusts and a few tornadoes ranging from EF0 to EF1 and affecting seven (7) counties. The most property damage was recorded in Bell County ($250,000) and Christian County ($104,000).

- **May 2, 2010:** A broken cluster of severe thunderstorms with embedded supercells and small bow echoes moved east-northeastward across western KY. The two (7) primary supercells of the night followed similar paths across southern parts of the Purchase area, the Lakes region, and the southern Pennyrile region. Multiple tornados ranging from EF0 to EF2, affecting seven(7) counties: Fulton, Hickman, Graves, Christian, Hopkins, Monroe and Wayne. The highest recorded damage was recorded in Hickman ($300,000) and Christian County ($300,000).

- **May 8, 2009 (DR-1841):** A tornado touched down in eastern Garrard County south of Nina on Bethel Road. The first damage observed was of EF1 intensity and the tornado grew to EF2 before reaching the Madison County line. The tornado peaked EFE intensity in Madison County where a mobile home was picked up, thrown, and disintegrated. Two (2) adults were killed and thrown into a nearby pond. Five (5) other occupants of the mobile home were injured. On May 29, 2009, Federal Disaster DR-1841 was declared.

- **February 5, 2008 (DR-1746):** On this date a prolific tornado outbreak took place. There were at least 16 tornados which crossed central Kentucky. The outbreak included two EF3 tornadoes in three (3) counties. There were four (4) deaths in Allen County near Amos. The storm also included straight-line winds and gust which exceeded 100 mph in Nicholas County. On February 21, 2008 Presidential Disaster Declaration1746 was issued.

- **November 6, 2005 (DR-1617)**: On this date a long-track F3 tornado killed over 20 people in the Evansville, IN area**.** Two (2) more deadly tornadoes occurred later that month, each of which killed one (1) person. They were in Marshall County (KY) on **November 15, 2005**, and Ripley County (MO) on **November 27, 2005.** The most recent killer tornado in the Paducah County Warning Area was in Perry County, Missouri on **March 11, 2006.** Two persons were killed in this tornado. All the 2005-06 killer tornadoes were rated F2 or F3.

- **January 3, 2000:** F3 tornadoes struck Owensboro, Kentucky and Crittenden County, Kentucky on this date. These tornadoes demonstrate just how vulnerable this region is during the winter. These two (2) tornadoes caused about 70 million dollars in damage, along with a couple dozen injuries. **January 1999** was another active winter month,

with tornadoes on **January 21, 1999** and destructive severe thunderstorms on **January 17, 1999**.

- **March 18, 1925:** One of the most infamous tornadoes in U.S. history occurred in northern parts of the Paducah Warning Area. The Great Tri-state Tornado of March 18, 1925, was perhaps the deadliest and longest-lived in American history. This F5 tornado tracked an estimated 219 miles, killing 695 persons in its path. The tornado began near Ellington, Missouri and finally dissipated near Petersburg, Indiana. Jackson and Franklin Counties in southern Illinois suffered some of the most concentrated damage. Along a path from Gorham to West Frankfort, IL, 541 people were killed and 1,423 seriously injured in just 40 minutes. Despite the fact there was a continuous damage track, it is possible the Tri-state Tornado could have been a series of tornadoes instead of a single tornado.

Kentucky National Guard responds to tornado in West Liberty, Kentucky - 2012

Assessing Vulnerability by Jurisdiction: Tornado

Grid-Level Risk Assessment Model

Tornado Vulnerability Score = Exposure Score + Hazard Score

Assessing Kentucky's vulnerability to Tornado was determined through first calculating the Tornado Hazard Score. The Tornado Hazard Score was calculated by studying one (1) specific data source. The data layer used to create the Tornado Hazard Score was collected from the National Weather Service SVRGIS tornado path (1950-2012) GIS data layer.

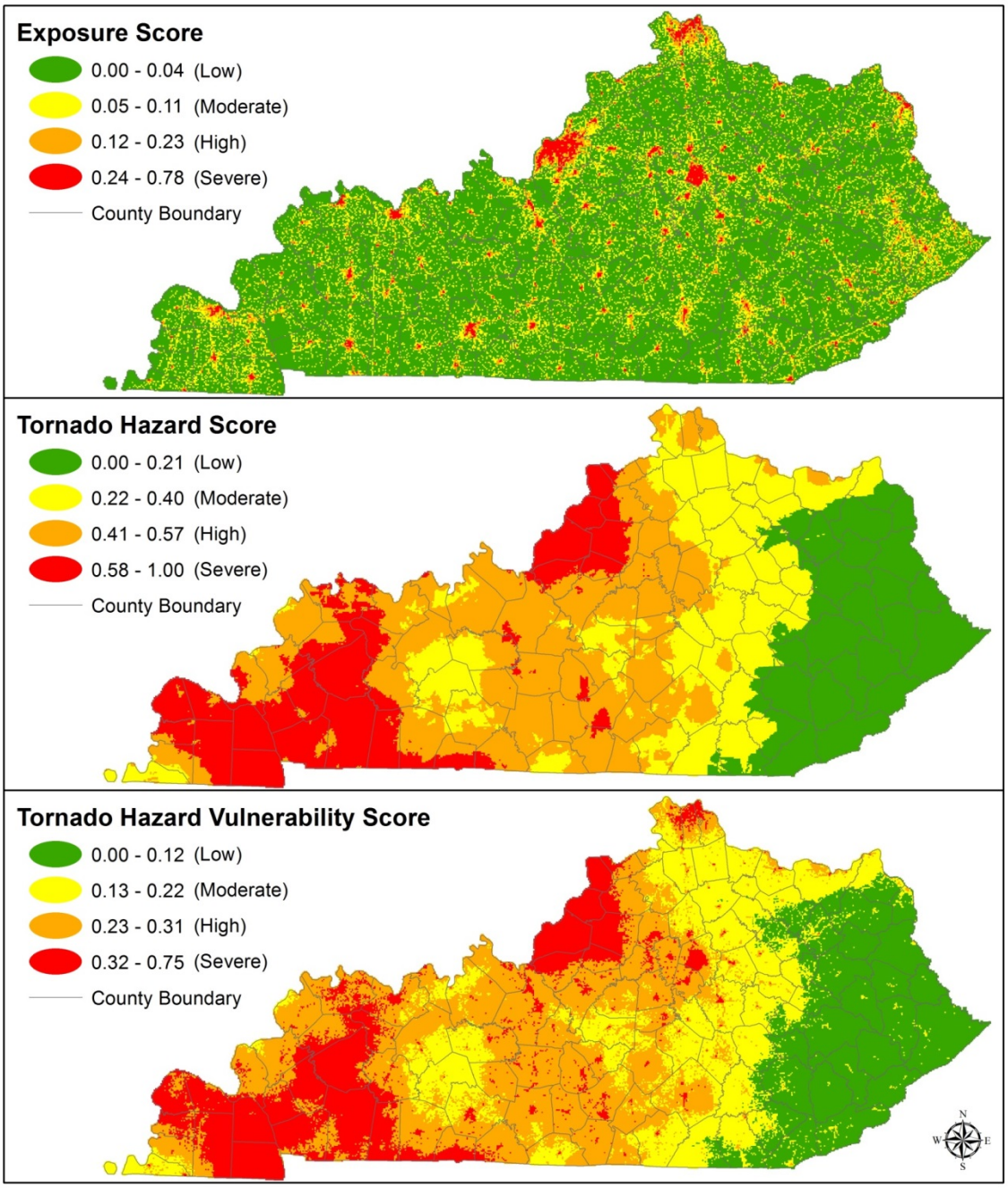
For analyzing this data CHR used a 25 mile radius to calculate each 1 KM MGRS grids geographic risk from a tornado event. The 25-mile radius was selected because that is the distance that the National Weather Service uses when producing severe weather alerts and probability maps. Basically, the 25 mile radius reduces the white noise and randomness present in atmospheric event data, which enables a meaningful picture of the risk to each grid, built based on historic rates of occurrence in the area. These 25 mile radiuses create map layers that were used as the base map layer for Tornado Hazard Score.

To analyze Kentucky's risk to Tornado, the 25 mile radius tornado path layer was overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based on the total number of tornado events that occurred within a 25 mile radius of each grid. Each grid was then calculated and scored 0-1 to develop the Tornado Hazard Score.

The Tornado Vulnerability Score was calculated for each 1 KM MGRS grid by adding each grid's Exposure Score by its Tornado Hazard Score and then scored 0-1. Once the final Tornado Vulnerability Scores were calculated the composite scores were broken into four (4) categories, using the Natural Breaks classification system (1. Low, 2. Moderate, 3. High, 4. Severe), which demonstrates different levels of vulnerability displayed on the map.

The Grid-Level Risk Assessment Model should be used to identify specific areas of vulnerability located throughout Kentucky. This model provides 106,178 equal areas of comparison for the end users to assess hazard vulnerability. The best way to view and use this data is through a GIS viewer.

The following map displays the maps and components of the Tornado Vulnerability Score.



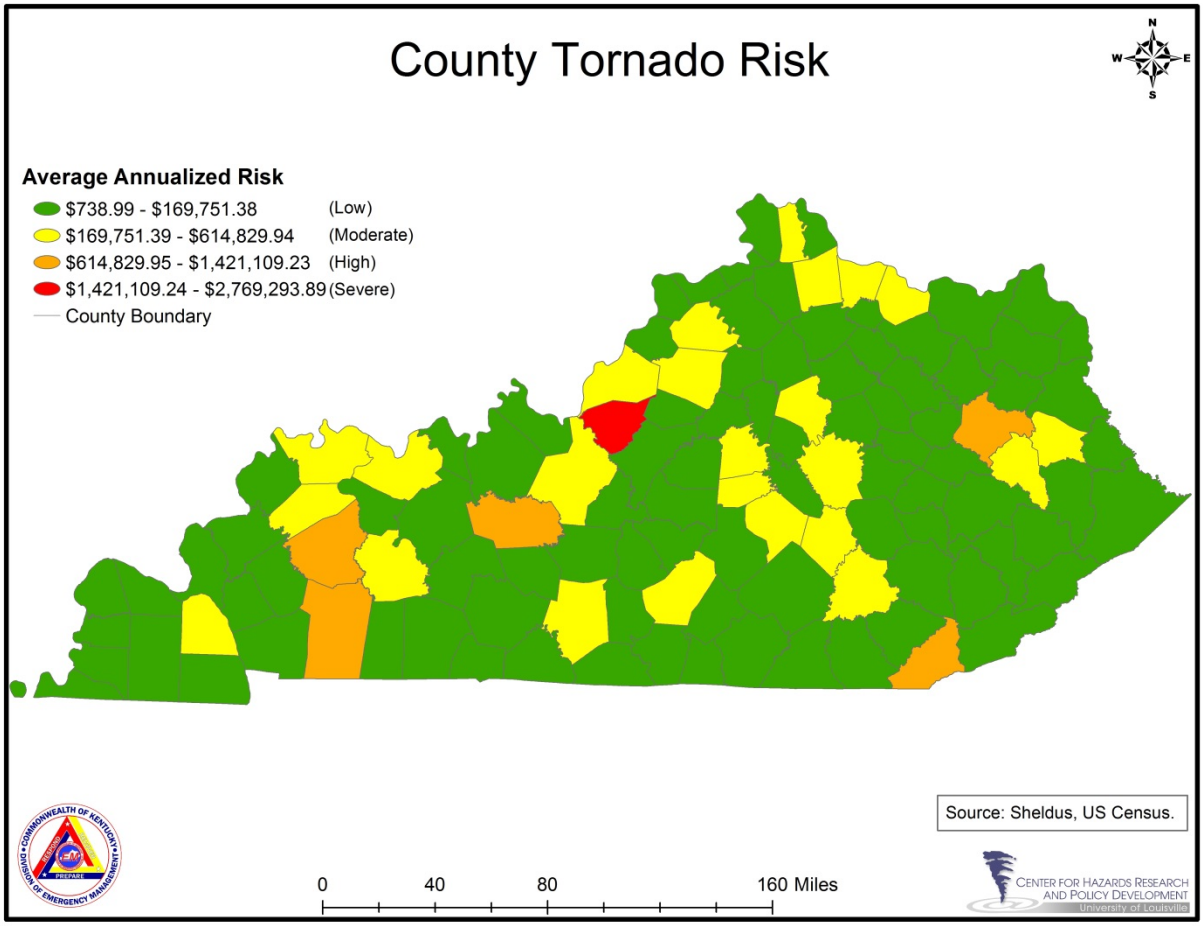
Source: Exposure- Division of State Risk and Insurance, ESRI, Kentucky Infrastructure Authority, Kentucky Office of Geographic Information, Kentucky Transportation Cabinet, KYEM, Public Service Commission, and the US Census Bureau. Hazard: NOAA

0 30 60 120 Miles

CENTER FOR HAZARDS RESEARCH AND POLICY DEVELOPMENT
University of Louisville

County-Level Risk Assessment Model

The Tornado County Risk Assessment Model was created using the Tornado Average Annual Loss data for each county. The average annual loss is calculated by multiplying each county's annual rate of occurrence by their average losses (See ***Appendix 3-2*** "Hazard Average Annualized Loss"). This data was then joined to a county map for display as seen below.



The County-Level Risk Assessment Model should be used to compare county-level risk. This data depicts which counties are experiencing the most occurrences and losses from tornados comparatively across Kentucky.

Hazard Category: HUMAN-MADE

Dam Failure

Identifying Hazards: Dam Failure

Description

There are more than 80,000 dams in the United States, the majority of which are privately owned. Other owners are state and local authorities, public utilities, and federal agencies. The benefits of dams are numerous; providing water for drinking, navigation, and agricultural irrigation. Dams also provide hydroelectric power and create lakes for fishing and recreation. Most importantly, dams are important mitigation effort that save lives by preventing or reducing floods.

Dams, though providing many benefits, can pose a risk to communities if not designed, operated, and maintained properly. In the event of a dam failure, the energy of the water stored behind even a small dam is capable of causing loss of life and great damage if there are people and properties downstream of the dam. The National Dam Safety Program (NDSP), led by FEMA, is dedicated to protecting the lives of citizens and their property from the risks associated with the development, operation, and maintenance of America's dams.

Types

Manmade dams may be classified by: 1) the type of materials used; 2) the methods used in construction; 3) the slope or cross-section of the dam; 4) the way the dam resists water pressure forces; 5) the means for controlling seepage; and 6) the purpose of the dam. Materials used for dams may include earth, rock, tailings from mining or milling, concrete, masonry, steel, timber, and miscellaneous materials such as plastic or rubber.

- *Embankment dams,* the most common type of dam in use today, are made from materials which include natural soil or rock, or waste materials obtained from mining or milling operations. An embankment dam is termed an “earth-fill” or “rock-fill” dam depending on whether it is comprised of compacted earth or of dumped rock. The ability of an embankment dam to resist the reservoir water pressure is primarily a result of the mass weight and the type and strength of the materials from which the dam is made.

- *Concrete dams* may be categorized as gravity or arch dams according to the design used to resist the stress of reservoir water pressure. Concrete gravity dams use the mass weight of concrete and friction to resist reservoir water pressure. A buttress dam is a specific type of gravity dam in which the large mass of concrete is reduced, and the forces are diverted to the dam foundation through vertical or sloping buttresses.

- *Concrete arch dams* are typically thin in cross-section. The reservoir water forces acting on an arch dam are carried laterally into the abutments. The shape of the arch may resemble a segment of a circle or an ellipse, and the arch may be curved in the vertical plane as well. Such dams are usually constructed of a series of thin vertical blocks that are keyed together with barriers to stop water from flowing between the blocks.

- *Coal impoundments* are defined by the Mining Safety and Health Administration (MSHA) as any structure associated with coal mining operations built to impound water and are either 20 feet high or capable of impounding 20 acre feet of water. Coal impoundments store coal slurry comprised of wastewater and impurities that result from coal washing and processing. A bulkhead or embankment is made of coarse coal refuse and acts as a dam. Behind it lies a pond of coal slurry. Sediment settles out of this turbid mixture, filling the pond, while wastewater is recycled back into the coal washing process. The sizes of the ponds and bulkheads vary, but pond basins are often hundreds of feet deep and hold millions of gallons of slurry. Coal impoundment failures have resulted in property damage, environmental contamination and, in one case, loss of life.

Dam classifications are based on the evaluation of damage possible downstream. The FEMA guide to dam classifications uses the following system:

Classification of Dams	
Classification	Description
Class A (Low)	No loss of human life is expected and damage will only occur to the dam owner's property
Class B (Moderate/Significant)	Loss of human life is not probable, but economic loss, environmental damage, and/or disruption of lifeline facilities can be expected
Class C (High)	Loss of one or more human lives is expected

Source: FEMA 333; Federal Guidelines for Dam Safety, Hazard Potential Classifications

Facts

- There are 84,134 dams listed in the National Inventory of Dams (2010 database).
- Only 3.8% of the dams are owned by the federal government.
- 87% of the dams in the inventory are earthen dams.
- 1,595 significant hazard dams are within one mile of a downstream city.
- The average age of a dam is 55 years.

Signs of Potential Dam Failure

- *Seepage.* The appearance of seepage on the downstream slope, abutments, or downstream area is cause for concern. If the water is muddy and is coming from a well-defined hole, material is probably being eroded from inside the embankment and a potentially dangerous situation can develop.

- *Erosion.* Erosion on the dam and spillway is one of the most evident signs of danger. The size of erosion channels and gullies can increase greatly with slight amounts of rainfall.

- *Cracks.* Cracks are of two types: traverse and longitudinal. Traverse cracks appear perpendicular to the axis of the dam and indicate settlement of the dam. Longitudinal cracks run parallel to the axis of the dam and may be the signal for a slide, or slump, on either face of the dam.

- *Slides and Slumps.* A massive slide can mean catastrophic failure of the dam. Slides occur for many reasons and their occurrence can mean a major reconstruction effort.

- *Subsidence.* Subsidence is the vertical movement of the foundation materials due to failure of consolidation. Rate of subsidence may be so slow that it can go unnoticed without proper inspection. Foundation settlement is the result of placing the dam and reservoir on an area lacking suitable strength, or over collapsed caves or mines.

- *Structural.* Conduit separations or ruptures can result in water leaking into the embankment and subsequent weakening of the dam. Pipe collapse can result in hydraulic failures due to diminished capacity.

- *Vegetation.* A prominent danger signal is the appearance of "wet environment" types of vegetation such as cattails, reeds, mosses and other wet area vegetation. These types of vegetation can be a sign of seepage.

- *Boils.* Boils indicate seepage water exiting under some pressure and typically occur in areas downstream of the dam.

- *Animal Burrows.* Animal burrows are a potential danger since such activity can undermine the structural integrity of the dam.

- *Debris.* Debris on dams and spillways can reduce the function of spillways, damage structures and valves, and destroy vegetative cover.

Types of Failures

- *Hydraulic Failure.* Hydraulic failures result from the uncontrolled flow of water over the dam, around the dam and adjacent to the dam, and the erosive action of water on the dam and its foundation. Earth dams are particularly vulnerable to hydraulic failure since earth erodes at relatively small velocities.

- *Seepage Failure.* All dams exhibit some seepage that must be controlled in velocity and amount. Seepage occurs both through the dam and the foundation. If uncontrolled, seepage can erode material from the foundation of an earth dam to form a conduit through which water can pass. This passing of water often leads to a complete failure of the structure, known as piping.

- *Structural Failure.* Structural failures involve the rupture of the dam or its foundation. This is particularly a hazard for large dams and for dams built of low strength materials such as silts, slag, fly ash, etc. Dam failures generally result from a complex interrelationship of several failure modes. Uncontrolled seepage may weaken the soils and lead to a structural failure. Structural failure may shorten the seepage path and lead to a piping failure. Surface erosion may lead to structural or piping failures.

Impacts

Dam failures cause flooding much different from natural flooding. A flood from a dam failure may arrive before any warning or evacuation can occur and the resulting wall-of-water makes evacuation based on limited environmental cues very problematic. The failure of large dams results in flooding with enough energy to damage or destroy residences and other structures

Profiling Hazards: Dam Failure

DAM FAILURE PROFILE RISK TABLE	
Period of occurrence:	Failure can occur at any time, but is often spurred by other events such as heavy flooding or seismic activity
Number of events: (1973-2013)	13*
Annual Rate of Occurrence:	0.43
Warning time:	Warning time is minimal and can often be directly related to frequency and thoroughness of inspections
Potential impacts:	Impacts on human life and public safety. Economic loss, environmental damage, and disruption of lifeline facilities.
Recorded losses:	Unknown based on lack of data capture
Annualized Loss:	Unknown based on lack of recorded losses
Extent (Date, Damages, Scale/Size):	Years: 1981, 2000 Damage: 1 fatality, 250 million gallons of slurry release.

*Data captured from National Performance Dam Program and Dam Safety.org

The state of Kentucky has over 1,000 dams, with almost 300 dams being identified by FEMA as High Hazard - or Class C - dams. According to the National Performance of Dams Program's database, eleven (11) dam malfunctions have been reported in the state of Kentucky since 1973, with seven of those being complete dam failures.

Dam malfunctions and failures can occur at any time during the year, day or night and certain types of damages can be prevented with regular inspection and maintenance.

Coal impoundments also pose a severe threat to the human populations and the environment in the event of failure. According to the MSHA, of the 713 impoundments nationwide, 121 are found in Kentucky and 60 of those are high risk impoundments in terms of retaining failure.

Listed in the following table are the historical dam malfunction events for the state of Kentucky, as well as information on impoundment failure and current dam projects occurring in the state.

Kentucky Dam Malfunctions, 1973-Present				
NPDP ID	Dam Name	Incident Date	Incident Type	Dam Failure
KY00137	Caulk Lake Dam	12/16/1973	Seepage	Yes
KY00003	Camp Ernst Dam	9/15/1978	Embankment Slide	Yes
KYS00007	East Fork Pond River FRS No. 4.1	12/8/1978	Foundation Failure	Yes
KYS00004	Samsel	2/2/1979	Seepage	No
KYS00006	Eastover Mining Company Dam	12/18/1981	Sabotage - Other	Yes
KY00014	Indian Lake Dam	1983	Piping	Yes
KYS00005	Unnamed Dam	1989	Inflow Flood - Hydrologic Event	Yes
N/A	Treasure Lake (Boone Co)	02/1993	Overtopping – 32' Hugh damn, 15 acre lake.	No
KY00036	Kincaid Creek Dam	3/1/1997	Inflow Flood - Hydrologic Event	No
KY00345	Mud River Mps #6a	3/1/1997	Inflow Flood - Hydrologic Event	No
KY00040	Guist Creek Lake Dam	3/1/1997	Inflow Flood - Hydrologic Event	No
KY00174	Hematite	6/11/1998	Not Known;Seepage;Piping	Yes
N/A	Inez (Martin Co)	10/11/2000	Tailings dam failure from collapse of an underground mine beneath the slurry impoundment. 250 million gallons (950,000 m3) of coal waste slurry released into local streams	Not a damn failure but a failure of the floor of the reservoir into the mine

http://npdp.stanford.edu/index.html
http://www.damsafety.org/media/Documents/PRESS/US_FailuresIncidents.pdf
http://www.wise-uranium.org/mdaf.html

On October 11, 2000, the Big Sandy River in Inez, Kentucky ran black with thick coal sludge. An abandoned mine below the coal impoundment near Inez collapsed, freeing 250 million gallons of refuse coal slurry from the impoundment pond. It flooded the mineshaft and spilled out into local rivers and streams, overflowing riverbanks and swamping backyards and roads with tar-like black muck.

Inez schools and businesses closed and some Kentucky towns advised residents to boil their water. Nearby communities in West Virginia rerouted drinking water pipelines to avoid slurry contamination.

The Environmental Protection Agency (EPA) calls the aftermath of the Inez impoundment collapse one of the worst environmental disasters to have ever occurred in the South.

Alternatives to coal impoundments include injecting the slurry underground, designing power plants to use impure coal, and cleaning coal using magnets and electrostatic forces, not water. With less coal slurry and fewer coal impoundments, the risk of dangerous impoundment failure is lessened.

The Wolf Creek Dam is on the Cumberland River in the Western part of Russell County, Kentucky. It was constructed to generate hydroelectricity and prevent flooding but is better known for creating Lake Cumberland, which has become a popular tourist attraction and is also the largest man-made lake, by volume, east of the Mississippi River. Lake Cumberland, along with Dale Hollow Dam, Center Hill Dam and J. Percy Priest Dam, provide an adequate supply of water to enhance navigation on the mainstream the Cumberland River from Celina, Tennessee, to the Ohio River. The lake is a source of recreation which has attracted more visitors (4.89 million) than Yellowstone National Park (2.87 million). Designed and constructed during the period 1938-1951, the 5,736 foot-long dam is a combination of rolled earth fill and concrete gravity structure.

From 1968 through 1979, efforts were made to respond to technical issues affecting the dam with water undercutting the dam at its base. By the end of 1979 the Corps of Engineers had conducted a "grout" campaign as well as constructed a concrete dam in front of the earthen dam to assist in maintaining water in the Lake. In 2005, the dam was discovered to have developed leaks under the earthen part of the dam. The center of the earthen dam is filled with a concrete slab which has already been extended. Minor repairs were scheduled in 2006 with major repairs beginning in 2007. As of April 2013, the U.S. Army Corps of Engineers announced the $594 million project would be finished ahead of schedule sometime in the spring of 2013.

KYEM has been directly involved since 2005 with the development of a joint dam planning group, consisting of the Corps of Engineer, Federal Emergency Management Agency, and emergency management Representatives from Clint, Cumberland, Monroe, and Russell Counties. Evacuation and sheltering plans were developed in coordination with the Wolf Creek Dam Emergency Action Plan. The plans are reviewed and updated as required and will be in effect until such time as the rehabilitation projects managed by the Corps of Engineers is finished.

Assessing Vulnerability by Jurisdiction: Dam Failure

Grid-Level Risk Assessment Model

Dam Failure Vulnerability Score = Exposure Score + Hazard Score

Assessing Kentucky's vulnerability to Dam Failure was determined through first calculating the Dam Failure Hazard Score. The Dam Failure Hazard Score was calculated by studying three (3) sources of data. The first layer used to create the Dam Failure Hazard Score was the newly created KDOW dam inundation maps along with the DFIRM mapped X zones that displayed areas protected by levees. These two (2) layers display a geo-referenced data that depicts where dam and levee failures could occur. To analyze Kentucky's risk to Dam Failure according to these data layers, they were overlaid onto a map of 1 KM MGRS grids in Kentucky. Next, a calculation was computed based on the percent of the area the dam inundation and mapped levee areas covered within each grid. This percentage of area affected by the mapped layers was then calculated and scored 0-1 to develop 50% of the Dam Failure Hazard Score.

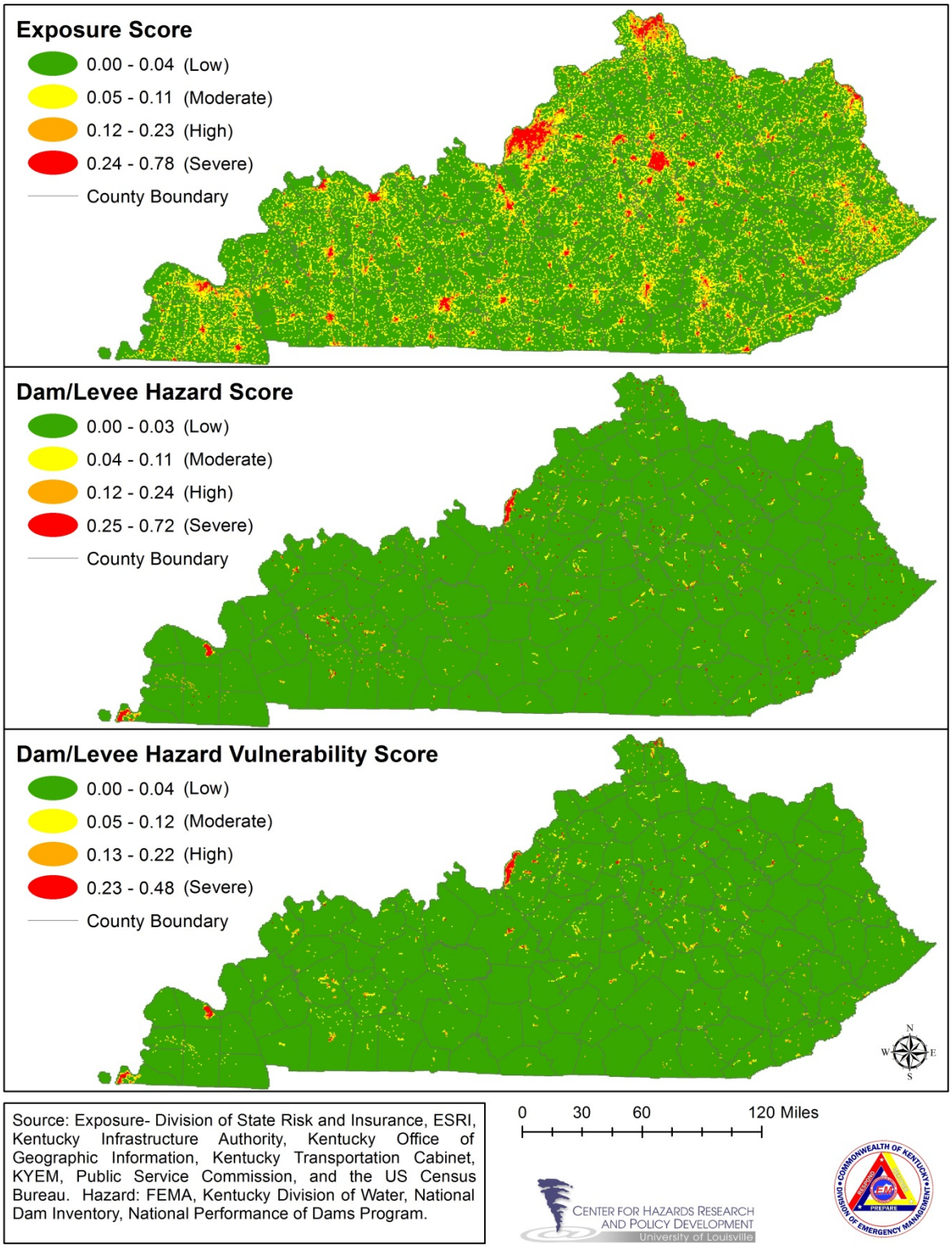
The next step was determined by counting the total number of dams located within each 1 KM MGRS grid. This data displayed where concentrations of Dam Failure events have occurred, thus producing areas of risk. In order to calculate different severities of risk based on dam risk classifications each dam was rated as high, medium, and low hazard dams according to Federal Guidelines for Dam Safety Classifications (2004). A high hazard dam was given a score of 3, medium a score of 2, and low a score of 1. Once all the scored dam location points were aggregated to their appropriate grid, each grid was giving a score 0-1 to create the other 50% of the Dam Failure Hazard Score.

The Dam Failure Hazard Score was then calculated by adding the two (2) scores together and scored 0-1. It is important to note if the Dam Failure Hazard Score inputs equaled 0, then the Dam Failure Hazard Vulnerability Score equaled 0.

Finally, the Dam Failure Vulnerability Score was calculated for each 1 KM MGRS grid by adding each grid's Exposure Score by its Dam Failure Hazard Score and then scored 0-1. Once the final Dam Failure Vulnerability Scores were calculated the composite scores were broken into four (4) categories, using the Natural Breaks classification system (1. Low, 2. Moderate, 3. High, 4. Severe), which demonstrates different levels of vulnerability displayed on the map.

The Grid-Level Risk Assessment Model should be used to identify specific areas of vulnerability located throughout Kentucky. This model provides 106,178 equal areas of comparison for the end users to assess hazard vulnerability. The best way to view and use this data is through a GIS viewer.

The following map displays the maps and components of the Dam Failure Vulnerability Score.



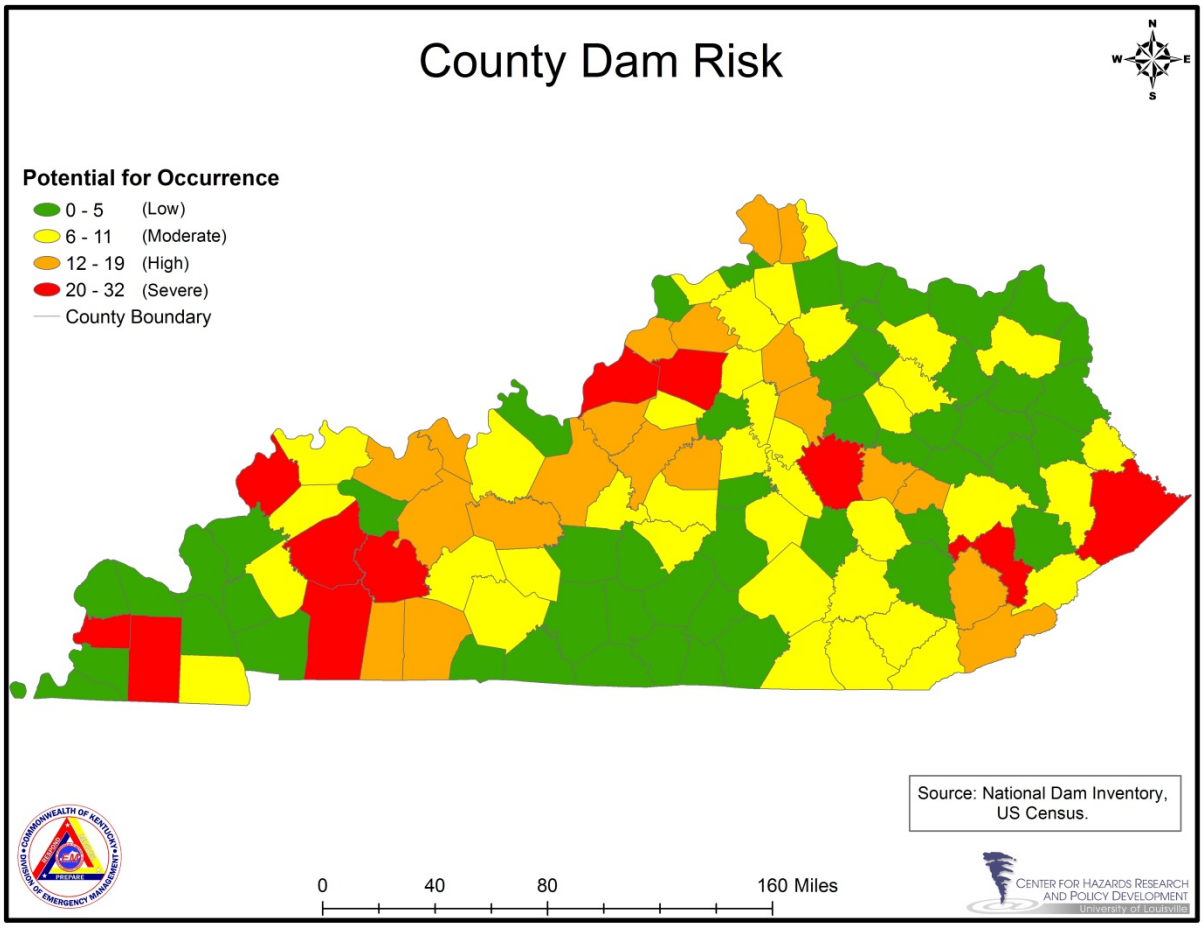
Source: Exposure- Division of State Risk and Insurance, ESRI, Kentucky Infrastructure Authority, Kentucky Office of Geographic Information, Kentucky Transportation Cabinet, KYEM, Public Service Commission, and the US Census Bureau. Hazard: FEMA, Kentucky Division of Water, National Dam Inventory, National Performance of Dams Program.

0 30 60 120 Miles

CENTER FOR HAZARDS RESEARCH AND POLICY DEVELOPMENT
University of Louisville

County-Level Risk Assessment Model

The Dam Failure County Risk Assessment Model was created based on the total number of dams per county. Each dam was assigned to their appropriate county and was then calculated to provide a total number of dams per county layer. This data was then joined to a county map for display as seen below.



The County-Level Risk Assessment Model should be used to compare county-level risk. This data depicts which counties have the most dams comparatively across Kentucky.

A Note on Other Types of Human-Made Hazards

Kentucky Revised Statute (KRS) 39A.010 ultimately lists the following "threats to public safety and health" that, using Threat and Hazard Identification and Risk Assessment (THIRA) criteria, have been categorized by Kentucky as "human-made[10]":

- Enemy Attack
- Nuclear Weapons
- Chemical Weapons
- Biological Agents
- Sabotage
- Riot
- Civil Disorder
- Terrorism
- National Security Emergencies
- Explosions
- Power Failure and/or Energy Shortages
- Major Utility System Failure
- Building Collapse
- Infrastructure Failure
- Transportation-Related Failures
- Hazardous Materials (HAZMAT)
- Mass Casualties/Fatalities
- Technological Emergencies Related to Cyber Technology
- Technological Emergencies *Not* Related to Cyber Technology

[10] "Dam Failure" falls within this "human-made" category, as well. It has been excluded from the list as it is an area formally addressed and analyzed above.

In the statute (KRS 39A.010), the above list is collapsed into categories as follows:

1) **Enemy Attack**
2) **Threats to Public Safety and Health Involving Nuclear, Chemical, and/or Biological Agents or Weapons**
3) **Acts of Terrorism**, Including: Sabotage, Rioting, Civil Disorder, Terrorism, Other National Security Emergencies
4) **Infrastructure Failure**, Including: Explosions, Power Failure and/or Energy Shortages, Major Utility System Failure, Building Collapse, Other Infrastructure Failure
5) **Transportation-Related Failures**
6) **Emergencies Caused by the Spill of Hazardous Materials (HAZMAT)**
7) **Mass Casualty/Mass Fatality Emergencies**
8) **Other**, Including: Technological Emergencies Related to Cyber Technology and Technological Emergencies *Not* Related to Cyber Technology (Biological, Etiological, Radiological, Environmental, Industrial, Agricultural Emergencies)

This 2013 Update of the Commonwealth of Kentucky's Hazard Mitigation Plan does not seek any substantial analysis of these abovementioned "human-made" threats. This is an area of emergency management and hazard mitigation in its infancy both within the state of Kentucky and nationally.

However, this is also an area of emergency management and hazard mitigation that currently is being pursued by the Commonwealth of Kentucky and toward which future planning will be required and subsequently directed.

To this point, the 2013 update of Kentucky's hazard mitigation plan has addressed such prefatory actions by the Commonwealth in its *Planning Process* section and has prepared mitigation actions that provide a basis upon which future planning for human-made hazards can be based. The latter is discussed in the *Mitigation Strategy* section of this plan and will be discussed below.

Consequently, a general discussion of vulnerability and of risk assessment related to human-made hazards is relevant here. The Federal Emergency Management Agency (FEMA) has provided considerable guidance regarding how the Commonwealth of Kentucky can begin its future pursuit to mitigate human-made hazards. The following discussion then will rely upon FEMA resources, namely its *Enhanced Threat and Risk Assessment* guidance,[11] that, when used is cited as FEMA [2009].

[11] Federal Emergency Management Agency (FEMA). [2009]. *Enhanced Threat and Risk Assessment: MGT-315: Participant Guide*. Washington, D.C.: U.S. Department of Homeland Security National Training Program.

The first general idea to address is clarifying the list of human-made hazards (i.e. “threats to public safety and health”) deriving from the Kentucky Revised Statute (39A.010) mentioned above. The individual categories in the list do not necessarily carry equal weight and worth in analysis. There is an underlying framework by which to organize the human-made hazards identified so that a systematic and useful analysis eventually can be performed.

Kentucky Revised Statute 39A.010 arguably juxtaposes both causes with their effects and ends with their means.

Addressing the former, within the KRS 39A.010 list, “enemy attack” and “acts of terrorism” should be prioritized: “Enemy attack” and “acts of terrorism” are causes. From the KRS 39A.010 list, its effects possibly include: “explosions,” “power failures,” “major utility system failure,” “building collapse,” “infrastructure failure,” “transportation-related failures,” “technological emergencies,” and “mass casualties/fatalities.”

Addressing the argument that KRS 39A.010 juxtaposes ends with their means, again “acts of terrorism” is the highlight: “nuclear weapons,” “chemical weapons,” “biological agents,” “sabotage (as a mean instead of an effect),” and “technological emergencies” are all means by which terrorists (rioters, disobedient civilians, saboteurs et al.) would achieve their ends.

This is, of course, not to say that those items on the KRS 39A.010 list that are likely to be *effects* from causes and *means* to ends should not be addressed separately: Effects can, of course be causes and means can, of course, be ends given change in context. A “major utility system failure” does not have to be an effect. It can certainly be a cause for “infrastructure failure,” “building collapse,” “transportation-related failures,” “civil disorder,” and “mass casualties and fatalities.” “Acts of terrorism” do not need to “cause” “major utility system failure.” Similarly, “acts of terrorism” do not have to be the end for there to exist danger from “nuclear weapons,” “chemical weapons,” and “biological agents.” Protecting populations from the harmful effects of nuclear/chemical/biological weaponry need not consider a calculated motive or spontaneous uprising as the hazards’ catalyst. These items are dangerous all on their own.

However, when it comes to mitigation measures and strategy, “enemy attack” and “acts of terrorism” do provide a tie that binds or a framework that underlies most of the human-made hazards listed in KRS 39A.010. “Enemy attack” and “acts of terrorism” ultimately describe a motive (even in the case of spontaneous rioting and civil disobedience). Granted, while a motive is not necessary, (i.e. whether the metempsychosis of premillennial caliphs animates the act of terrorism or whether Homer Simpson falls into a sugar coma at the control switch means little to the effects resulting from a “HAZMAT” leak), focusing planning and mitigation strategies on enemy attacks and acts of terrorism do imply mitigating *the effects from enemy attacks and acts of terrorism* so that terrorism does not *need* to be the cause of the danger: The Commonwealth of Kentucky protects against “major utility system failure” by assuming it

is, with motive, being attacked even if it is, in fact, not being attacked and is simply failing due to poor maintenance.

In other words, using the hazards identified in KRS 39A.010 and categorized as "human-made" using THIRA criteria, focusing planning and mitigation activity on terrorism acts as planning for a "worst-case scenario." Power failures and HAZMAT issues do not have to come about as the result of malign intent via attack; but, planning as if attack was the cause provides the most comprehensive planning for those hazards.

Anchoring human-made hazard risk analysis (of those hazards identified in KRS 39A.010) to terrorism, or, more generally, to an attack, sets one immediate priority onto which the Commonwealth of Kentucky can focus its risk assessment and planning activities: The Commonwealth-wide identification of critical facilities.

Such identification would likely involve at least three (3) "phases[12]":

- ***Phase 1:*** *Commonwealth-wide identification and compilation of local jurisdictions' critical facilities.* This will literally be a count; the identification of individual data points.

- ***Phase 2:*** *The identification of the relationship/connection between individual critical facilities:* Critical facilities are rarely stand-alone edifices and functions. By their very nature and definition (i.e. they are *critical*), such facilities will be tied to or "nested" within networks of other likely critical facilities or to some larger system. For example, a power plant toward which the Commonwealth would want to mitigate the effects of "power failure" or "energy shortage" is connected to a distribution system that includes substations connected to transformers connected to individual houses, schools, and commercial structures. Many of these facilities within the power plant's distribution network also would be "critical." Such distribution system identification, or networking, especially apply if the Commonwealth of Kentucky includes "technological emergencies" as either means (to cause) or effects resulting in human-made hazards: Technology, again by nature, is imbedded ("nested") into larger systems.

- ***Phase 3:*** *The individual identification of vulnerabilities within the now-identified critical facilities nested with systems of critical facilities*. By this phase, the Commonwealth of Kentucky ideally will have a full list of individual critical facilities accompanied by further spatial data regarding with which, within which, or amidst which facilities the items on this list are linked, nested, and/or related. Knowing *which* of Kentucky's facilities is "critical" and *how* these facilities are related to other critical facilities finally allows a vulnerability assessment from *within* the individual critical facilities themselves.

[12] These "phases" have been identified as some of the Commonwealth of Kentucky's mitigation actions, as well.

A Brief Discussion of Vulnerability to Human-Made Hazards

Enemy attacks and acts of terrorism and the subsequent potential for threats to public safety and health involving nuclear, chemical, and/or biological agents or weapons; emergencies caused by the spill of hazardous materials; and/or mass casualties/mass fatalities that they would cause imply a mitigation strategy founded in assessing vulnerability in structures, especially "critical facilities." Transportation infrastructure, security infrastructure, and structures that provide a vital need for a community or population, et al. will be targeted by enemy attacks and acts of terrorism and will be the confines in or onto which nuclear/chemical/biological agents/weapons, HAZMAT, and mass casualties/mass fatalities are released, spilt, and occur.

When the Commonwealth of Kentucky becomes able to begin identifying the vulnerabilities within its individual critical facilities (i.e. after the abovementioned *Phase 1* and *Phase 2* are complete), the following general, universal concerns likely will be apparent:

1) That there may be a lack of sufficient security
2) That there may be a lack of organizational culture that would play a substantial role in ensuring sufficient security
3) That there may be a lack of or irregular maintenance
4) That there may be deficiencies, inconsistencies, etc. in whom has access to a facility or how the facility is accessed

Beyond these vulnerabilities common to any type of critical facility nested within any network, one might identify the following relevant vulnerabilities specific to the targets of enemy attack and acts of terrorism and/or susceptible to threats to public safety and health involving nuclear, chemical, and/or biological agents and/or weapons; hazardous materials emergencies; and/or mass casualties/mass fatalities:

Assessing Vulnerability: Infrastructure Failure

The vulnerability of infrastructure generally looks similar to the abovementioned universal vulnerability concerns:

VULNERABILITY	ELABORATION
Lack of sufficient security to protect assets	The critical facility may be deficient in maintaining adequate security over the resources/assets/people it houses. The level of security may not match the criticality of the assets protected.
Lack of organizational culture supporting security; lack of employee security awareness	Those working within the critical facility and are not a member of the security team likely will pay less attention to and report less incidents and situations that expose or exploit vulnerabilities.
Lack of, irregular maintenance, especially around secure areas	Even if security measures are implemented, they must be maintained. A frequent vulnerability surrounds such security measures not being maintained: Broken locks, holes in security fencing, and lack of or burnt-out lighting around secure areas are common examples.
Deficiencies, inconsistencies, etc. in whom has access to a facility or how the facility is accessed; access control	Unauthorized access to restricted or controlled areas is an all-too-common vulnerability to critical facilities. This vulnerability is especially egregious to personnel not directly employed by the critical facility, i.e. external personnel.

Source: FEMA [2009]

However, specific types of infrastructure and their vulnerability to failure require additional consideration:

Waterfront/Port Infrastructure Vulnerabilities

Waterfront/Port Infrastructure

VULNERABILITY	ELABORATION
Act of terrorism/Attack deriving from ground, from air, from water	Ports necessarily are accessible from multiple transportation systems.
High cost and limited capability of sub-surface surveillance and response tools	Tools such as sonar, floating barriers, etc. that are frequently used by the United States Navy and United States Coast Guard are far more cost-prohibitive than grounded security tools and equipment.
Minimal resources and training necessary to attack from water	Those who seek to attack critical facilities have an advantage if the facility is on a waterfront or is a port or is in water: SCUBA gear is commercially available and is affordable; SCUB A dive-training is relatively inexpensive. Meanwhile, the attacks that SCUBA gear and training would allow are especially showy and destructive.
Difficulty in restricting access to waterfront facilities	Waterfront facilities and areas generally are open to the public. This has as much to do with futility as it does demand for and purpose of waterfront facilities: The public may as well be allowed in many places near water because it is highly cost-prohibitive to exclude. However, this also means that attacks using watercraft and SCUBA gear can "hide in plain sight" and operate unrestricted near critical assets.

Source: FEMA [2009]

Distribution System Infrastructure Vulnerabilities

"Distribution systems are vast and complex and require computer-based control systems to keep them operating at peak efficiency. They are used in many industries to monitor and control sensitive processes and physical functions. Control systems perform important functions in many of our nation's critical infrastructures… [FEMA 2009[13], p. 4-26]."

Basically, there exist two (2) types of control system: *distributed control systems* and *Supervisory Control and Data Acquisition (SCADA) systems*. The former generally are used over small geographic areas or in a single generating or processing-type plant. SCADA systems, meanwhile, are implemented over large geographic areas and toward dispersed function and operation.

Technological innovation and gains in efficiency guarantee, then, that SCADA systems are now widespread. Still, they are expensive both to implement and to maintain. Further, if disrupted in any way, such system failure creates considerable consequence for public safety. In protecting them, the following describes their general vulnerability:

VULNERABILITY	ELABORATION
Connectivity requirements to the internet and to other control systems	This is an inherent weakness in all control systems: Control systems – especially SCADA—automatically regulate the distribution of critical resources. In order to do so requires constant internet and intra-net activity. Major connectivity disruptions can lead to one part of the distribution system not communicating with another and, thus, regulation of distribution faltering or failing.
Inability to implement traditional network security protocols	SCADAs present significant technical challenges: They are real-time operations with limited processing capability and inherent system-design constraints that hinder the ability to implement what would be very typical network security protocols, e.g. "patches" and strong authentication passwords.

Source: FEMA [2009]

[13] Federal Emergency Management Agency (FEMA). [2009]. *Enhanced Threat and Risk Assessment: MGT-315: Participant Guide*. Washington, D.C.: U.S. Department of Homeland Security National Training Program.

However, there are additional vulnerabilities to consider regarding specific types of distribution infrastructure that use SCADA:

Electrical Distribution Infrastructure

VULNERABILITY	ELABORATION
Location of sub-stations	Sub-stations are usually located in isolated areas with subsequent minimal security around its critical components (i.e. the switches, circuit-breakers, transformers, ceramic insulators).
Substantial length of transmission lines	According to FEMA, the typical high-voltage transmission line (i.e. 155-765 kV) spans about 300 miles, end-to-end. Obviously, securing this 300-mile expanse is highly cost-prohibitive. These lines are vulnerable anywhere along their 300+ mile length.
Excessive power requirements leading overburdened electrical grid	Seasons of peak usage imply that high demand for power increases the likelihood that an electrical grid will shut down, causing a blackout. Blackouts are an especial vulnerability for those areas that heavily regulate the supply of electric power (e.g. politics slows the process of building new plants) and/or significantly subsidize the cost of electric power (thus artificially increasing demand for it).

Source: FEMA [2009]

Petroleum Distribution Infrastructure

VULNERABILITY	ELABORATION
Refineries	Refineries, as a consequence of design and purpose, are vulnerable to all manner of hazard, particularly natural hazard and hazards as a result of industrial accident. Further, as a consequence of their importance, refineries are target for attack, either intentional or spontaneous.
Pipelines	The United States houses thousands of miles of petroleum-carrying pipeline. For the most part and due mainly to the cost-prohibitive nature of it, these pipelines are unprotected.
Oil spills	Petroleum distribution infrastructure is always vulnerable to oil spills. This is a consequence of the nature of the product being distributed and of probability. Just as probability ensures that a Wal-Mart distribution chain will lose small portions of its products, so probability ensures that petroleum distribution chains will lose some of its product, as well. Lossless distribution does not exist.

Source: FEMA [2009]

Water Distribution Infrastructure

VULNERABILITY	ELABORATION
Access to points-of-origin	Water to be distributed originates from lakes, rivers, etc. It is highly cost-prohibitive and likely impossible to provide security around the shorelines of the large bodies of water supplying the distribution chain.
Access to points-of-distribution	The water distributed to fire hydrants and meters is likely entirely unprotected.
Systems dependent on water	A source of water distribution makes for a tempting target for attack as other hazard-prevention/mitigating systems are dependent on that water supply, e.g. cooling systems, the tools for fire suppression, et al.

Source: FEMA [2009]

Telecommunications Distribution Infrastructure

VULNERABILITY	ELABORATION
Simplicity of attack	Telecommunications refers to both cellular and wired networks. Attacks on these networks can be as simple as destroying one of the many and unguarded distribution paths governing a cellular or wired network, thus denying service
Simplicity of cell-phone network attack	More a sub-category of how simple it may be to attack telecommunications networks generally, cellular networks tend to have at least two (2) vulnerabilities related to "simplicity of attack": 1) They are easily hacked and 2) signals easily can be broadcast at cellular frequencies aimed toward cell towers.
Access to points-of-distribution	Related to cellular networks, cell towers and Mobile Telephone Switching Offices are critical to the network, are easily noticed, an usually lacking in any substantial security. Related to telecommunications networks generally, there are multiple points-of-distribution that are noticeable, easily accessed, and typically lightly secured. Examples of such points-of-distribution include: the Video-Ready Access Device (VRAD), which distributes television and internet services; the Cross-Connect Box (X-Box), which is a "telephone cabinet" primarily used by AT&T to distribute general communication services to its designated areas; and the Controlled-Environment Vault (CEV), which acts like AT&T's X-Box, but distributes telephony services more generally. CEV's are especially vulnerable as they frequently are placed in heavily-populated areas and provide distribution to critical facilities.

Source: FEMA [2009]

Building System Infrastructure Vulnerabilities

The "building system infrastructure" of most consequence to a critical facility is its Heating, Ventilation, and Air-Conditioning (HVAC) system. HVAC systems are the means by which a facility is able to bring in air from outside and mix it with air inside the facility while filtering out contaminants to create a pleasant environment within the facility. Comfort can be further manipulated through features like humidity-control, heating, and cooling that are controlled from some central access point(s).

HVAC systems typically are comprised of the following parts:

- Intakes that "take in" air from the outside;
- Ductwork;
- Air-handling Units (i.e., air filters, mixing chambers, supply fans, inputs);
- Heating and cooling systems;
- Humidity-control systems;
- Chillers, Boilers, and Cooling Towers;
- Return Air Systems;
- Exhaust Fans and Air Outlets; and
- Central Controls and Terminal Devices for the System

Consequently, HVAC systems are notoriously tempting targets for attack or for accident: They are central to the infrastructure of a facility. HVAC systems are connected to all parts of a facility via the facility's ductwork. Further, HVAC systems have multiple access points into which contaminants can be entered into a facility's duct system or that simply can be attacked.

Heating, Ventilation, and Air-Conditioning (HVAC) Infrastructure

VULNERABILITY	ELABORATION
Centrality to a Facility	In its function of bringing air from the outside of a facility and mixing with air on the inside and with its connection to all parts of facility via ducts, boilers, chillers, cooling towers, fans, and return air systems, an HVAC system makes for an ideal target.
Access points	Related to its centrality to a facility, the HVAC system's many parts that all have some connection to the duct-work within a facility and thus to the facility as a whole reveals another factor as to why they are ideal targets.
Duct Leakage/Irregular Maintenance	An HVAC system must be maintained regularly. One consequence and vulnerability resulting from irregular maintenance involves leakage in ductwork. Ducts must be sealed with less than 3% leakage. Otherwise, contaminants introduced into the HVAC system through its ductwork may spread to areas outside of the HVAC system's area.
Security layer	Again, related to an HVAC system's centrality within a facility, protecting the system may require multiple "layers" of security. For example, depending upon the sensitivity and criticality of a facility, it may detrimental to have HVAC systems connected thoroughly throughout the facility. Mailrooms, lobbies, mechanical rooms, and loading zones/docks may want to operate within different and segmented zones than the rest of the facility. Return-air systems or ceiling plenums may similarly want to be sequestered and not shared with other parts of the facility.

Source: FEMA [2009]

Information Technology (IT) System Infrastructure Vulnerabilities

The information technology (IT) system is the ultimate SCADA (Supervisory Control and Data Access) system: It is not exaggeration to claim that critical facilities themselves and critical facilities as nested in networks of facilities are utterly dependent upon IT systems.

Information Technology (IT) Infrastructure

VULNERABILITY	ELABORATION
Type of information to be targeted	IT systems oft maintain a facility's security system schematics; access codes and controls; facility emergency plans and site plans; the feeds from remote video-camera monitoring; employee/personnel personal information and work schedules; and digital controls for security systems, elevators, fire alarms, and HVAC systems. If IT systems can successfully be accessed, then they are ideal targets.
External internet connection: Lack of sufficient security	The IT system's primary vulnerability is through its external internet connection. Related to the general infrastructure failure vulnerability that there can be a lack of sufficient security, the external internet connection needs vigilantly maintained and updated firewalls, virus protections, and anti-spyware/anti-malware programs
External internet connection: Lack of organizational culture supporting security	The IT system's primary vulnerability is through its external internet connection. Related to the general infrastructure failure vulnerability that there can be a lack of organizational culture that supports/enforces security, the external internet connection needs to be protected through constantly updated security documentation, enforced computer usage and password policies, and the support of management.

Source: FEMA [2009]

Assessing Vulnerability: Transportation-Related Failure

"Transportation" is generally comprised of the following units and systems:

	By Air	By Land	By Water
Cargo-Bearing	• Hazardous Materials • Non-Hazardous Materials/Goods	• Hazardous Materials • Non-Hazardous Materials/Goods	• Hazardous Materials • Non-Hazardous Materials/Goods
People-Bearing	• Private Pilots, Passengers • Airline Pilots, Passengers, Crew • Emergency Responders	• Individual Drivers/Riders • Mass Transit Users/Drivers • Cargo Drivers • Emergency Responders	• Recreational Boaters, Boat Passengers • Commercial Mariners • Emergency Responders
Transport Sites	• Airports • Air Traffic Control Centers	• Roadways, Bridges • Bus, Rail Stations • Rail Yards, Rail Lines	• Public Waterways • Marinas, Ports • Cargo Terminals • Offshore Oil Platforms[14]
Vehicles	• Airplanes • Helicopters	• Cars, Motorcycles, Trucks • Buses, Trains, Subways	• Boats, Ships, Ferries • Container Ships, Tankers

Source: FEMA [2009]

The general vulnerability for most of the above units of transportation involves predictability: Predictable time schedules, predictable destinations, and predictable routes to arrive at destinations. Related, further vulnerability is a consequence of dependency upon these modes of transportation.

[14] Not relevant to Kentucky

The following is a more specific consideration of vulnerability for transportation-related infrastructure:

Transportation-Related Infrastructure

VULNERABILITY	ELABORATION
Attractive Targets	Transportation units are tempting targets for attack because of the likely potential for: - Mass casualties/mass fatalities - Far-reaching economic impact - Related, the disruption of national and international commerce/trade - Impacts to traffic flow - The inability/shutdown of emergency responses - The loss of confidence felt by the public toward public officials to protect them.
Major interstate or highway to enemy attack/act of terrorism	Specific to the general attractiveness of transportation systems as targets, a major interstate or highway is especially attractive as all of the effects listed above can be achieved logistically simply by an attack to an overpass or major artery.
Mass transit to enemy attack/act of terrorism	Again, specific to the general attractiveness of transportation systems as targets, mass transit is pointed out to clarify that while not as devastating or as effective a target to most areas of Kentucky, Kentucky does maintain some mass transit systems that would impact many individuals and disrupt economic activity if attacked.
Age/Reliability of existing infrastructure	According to FEMA, a majority of bridges, overpasses, and roadways have been identified as below-standard and, thus, subject to structural failure due simply to irregular maintenance and/or age.
Toxic materials	Daily, toxic materials travel the roadways and rail lines of Kentucky. An accident or an attack on just one of these modes of transport (e.g. one tanker-truck) carrying something as common as chlorine could lead to the deaths and/or injuries of hundreds of people.
Dependence on SCADA	Air and rail transport typically are operated by archaic computerized systems

Source: FEMA [2009]

Summarizing, then, considering the above general and hazard-specific vulnerabilities requires first an identification of all of the Commonwealth of Kentucky's critical facilities, and, second, an identification of the systems and networks within which individual critical facilities operate and/or are nested. Such a massive campaign is justified by assuming that of all of the human-made hazards identified in KRS 39A.010, enemy attack and acts of terrorism are the cause from which the Commonwealth of Kentucky should seek to protect its denizens. Enemy attack and acts of terrorism being the fulcrum used to turn the lever of mitigation activity aimed toward human-made hazard ensures a "worst-case scenario" mitigation strategy that is focused on Commonwealth-wide and system-wide identification of critical facilities and assets that otherwise might not take precedence outside attack ranked low in priority and if facilities were considered mutually exclusively.

While any or all of the abovementioned specific vulnerabilities can exist within any corresponding critical facility, we do not know which of the facility-specific vulnerabilities or to what extent each of the facility-specific vulnerabilities is affecting any one critical facility without knowing (a) that the "critical facility" is indeed critical and (b) within which system/network it is operating or is nested.

A (Very) Brief Discussion of Risk Assessment of Human-Made Hazards

Using enemy attack and acts of terrorism as the foundation for a discussion on vulnerabilities and risk assessment, the vulnerabilities to the Commonwealth of Kentucky from human-made hazards (at least as listed in KRS 39A.010) involves its infrastructure, especially related to transportation-related infrastructure and critical facilities.

Of the remaining human-made hazards that comprise the KRS 39A.010 list of categories[15], "vulnerability" is not at issue. Rather, "risk" is at issue. Human-made hazards such as "emergencies caused by the spill of hazardous materials (HAZMAT)" are not vulnerable in and of themselves. Rather, such hazards are the *source* of vulnerability mainly to infrastructure generally and both to transportation-related and critical, specifically.

"Risk," then, ultimately is a function of two variables: probability and magnitude of effect. Even after the source of a threat has been identified (e.g. we know specifically who will attack us) and even after the vulnerability of potential targets has been assessed, we cannot conceive of risk until we can assess the likelihood that an identified threat will strike and until we can assess how much damage (both monetarily and socially) will be wrought in the event of the identified threat whose likelihood of occurrence has been assessed.

The latter variable involved in "risk" (i.e. magnitude of effect) can be conceptualized: There is always enough information available validly to estimate to what degree of devastation an identified threat will call forth.

The immediate dilemma facing human-made hazards and the "risk" they present to vulnerable infrastructure and critical facilities involves "probability."

Probability, by its nature, is relative. What that means is that the likelihood of an event occurring cannot be claimed without that likelihood being in relation to some other event or variable. One cannot walk outside one's house on June 1st and simply claim that there is 85% chance of rain today. To justify such a probabilistic statement requires that that statement be related to some event or variable. It may look like an 85% chance of rain *in relation to* the dark and ominous nature of the sky upon walking out of the house. Similarly, the 85% statement can be justified if you know that, say, for 85 of the past 100 continuous years, June 1st has seen rain. There are, of course, problems with the above justifications; but, the point to be made is that probability requires relativity.

The caveat for the statement that "probability requires relativity" is that "relativity" or "relative-ness" can be defined and assumed as "random" and/or "independence." Here, the likelihood of an event occurring is still in relation to some other event or variable;

[15] Namely, "enemy attack;" "acts of terrorism;" "threats to public safety and health involving nuclear, chemical, and/or biological agents/weapons;" "emergencies caused by the spill of hazardous materials (HAZMAT);" "mass casualties/fatalities;" and "other," which includes technological emergencies both related and *un*related to cyber technology

only the relation is hypothetical: The likelihood of an event occurring in relation to the assumption that nothing external influences that likelihood.

Herein lies the dilemma and the source of future opportunity for the pursuance of assessing the risk of an event being caused by a human-made hazard: These causes are *not* random and are *not* independent; yet, they likely are "conditional[16]" upon an almost infinitesimal array of environmental, social, and political events and variables that (most importantly here) do not have to be historical in nature.

To this previous point, the relationship by which probability is deciphered when dealing with *natural* hazards is grounded in history as much as it is grounded in general environment and geography specifically[17]: A flood of some degree of magnitude is some percentage likely to occur in an area largely because floods of similar degrees of magnitude have occurred in this area repeatedly in the past, i.e. historically.

Human-made hazards do not give us such historical predictability. The variables upon which probability will be based are social, are political, are economic, and are psychological. In other words, the variables upon which probability for human-made hazards is based are infinite and dynamic. To add further complication, what historical points-of-relation do exist are rare and not connected necessarily: The bombing of a federal building in Oklahoma City in 1995 does not really say anything about the future likelihood of a bombing of a federal building in Louisville, Kentucky in 2014.

The point to be taken here is that risk assessment of human-made hazards is in its infancy. It is an area of emergency management and hazard mitigation that will be and is currently actively being pursued. Kentucky's immediate goals related to human-made hazards involves the prefatory data and variables that will later inform the probability underlying "risk" of a human-made hazard occurring: Kentucky seeks first to identify its critical facilities, to identify within which networks such critical facilities are nested, and then to use this information to assess how and where and to what magnitude individual critical facilities are vulnerable given what we know about their network and their purpose to a community or society generally. Until then and simultaneously, research will focus on how to conceptualize probability of human-made hazard events.

[16] Essentially, a human-made hazard occurs given the occurrence of some other cause or hazard.
[17] Even if it most likely true that geography *determines* the history of natural hazards, e.g. the flat plains characterizing the American West certainly determine the American West's history of tornado events.